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Biotechnology on the Battlefield: An Application of Agent-based Modelling for Emerging Technology Assessment

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ABSTRACT

Penetrating wounds are the most common injury incurred in military combat, resulting from both gunshot and shell fragmentation, and these wounds often result in mortality. However, in the future such fatal wounds might be treatable using advanced biotechnologies to control haemorrhaging and reduce blood-loss until medical evacuation can be completed. This study evaluates the operational implications of a new kind of intravenous coagulating agent. The efficacy of the drug is benchmarked against casualty data from the Vietnam War and assessed through a process of simulation in an agent-based combat environment. Finally, we conclude that the drug reduces mortality by 7%, within those casualties which are responsive to treatment.

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Executive Summary

Biotechnologies have the capacity to enhance the performance of combatants on the battlefield across a wide range of tasks and environments. The area of research is perceived to offer enormous potential benefit to Defence yet the obstacles to its practical employment are significant, especially within legal and ethical domains. In order to leverage these technologies and guide investment, Australia and its partner nations must be fully informed of the operational benefits that biotechnologies offer.

The range of biotechnologies of potential relevance is large. This report focuses on evaluating the operational benefit of one distinct technology which shows promise; that is, Haemostatic Nanoparticles for the treatment of combat wounds. This research is of particular interest because the drug is intravenous, meaning that it is effective in controlling internal bleeding including blunt trauma. While there are a range of treatments for compressible external wounds; including pressure dressings, tourniquets and topical materials; there are no analogous treatments (approved for human use) for controlling internal bleeding.

This report employs an agent-based methodology to analyse how military operations are affected by the adaptation of the emerging technology. A historical model of the Battle of Long Tan, Vietnam 1966, is developed for the purpose of situating the technology within the context of a designated military operation. This is essential because the validity of the model is established by accurately reproducing the historically documented operational dynamics and outcomes. The historical case study then acts as the benchmark against which the insertion of the emerging technology is assessed.

Through a process of simulation, the efficacy of Haemostatic Nanoparticles was evaluated. Our model determined that approximately 3.5% of combat fatalities could have been avoided if this advanced clotting agent was available to Australian forces at that time. A proportional reduction of 3.5% seems small, at first glance. However, only 50% of all battlefield fatalities are a result of exsanguination. Hence, the technology reduces mortality by 7% in wounds which are responsive to the treatment.

The particular drugs which have been developed using the technology are still in experimental phase and have yet to be approved for human trials. However, based on the information available to-date, we do conclude that the treatment is operationally effective. This coagulant, and other similar agents, will be of enormous benefit to Defence medical practice, assuming it becomes commercially available in the future.

Authors

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Scott Wheeler joined DSTO as a Research Scientist after completing a PhD in mathematics at the University of Adelaide. Scott previously managed the Complex Adaptive Systems Task in Land Operations Division at the DSTO Edinburgh site before moving to the Defence Systems Analysis Division in Canberra's Russell Offices. In Russell, Scott worked in the domain of Capability Analysis and was the Science Advisor to the Missile Defence Coordination Office. More recently he represented Australia as the National Lead for TTCP AG-14 Complex Adaptive Systems. Scott was previously a Visiting Research Fellow at the University of NSW, Australian Defence Force Academy and now works for the Joint and Operations Analysis Division DSTO in Fairbairn, Canberra.

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Acronyms

Acronym	Definition
ADO	Australian Defence Organisation
APC	Armoured Personnel Carrier
ATF	Australian Task Force
Bde	Brigade
Bty	Battery
CASEVAC Coy	Casualty Evacuation Company
DDR&E Div DSTO	Department of Defence Research and Engineering Division Defence Science and Technology Organisation
EDTAG ETAP	Emerging and Disruptive Technology Action Group Emerging Technology Analytical Panel
FFZ FO	Free Fire Zone Forward Observer
HQ	Headquarters
Inf	Infantry
JIC	Joint Innovation Centre
NVA NZ	North Vietnamese Army New Zealand
PA Pl	Project Arrangement Platoon
QTISP	Quinquupartite Technical Intelligence Steering Panel
RAAF RAR Regt	Royal Australian Air Force Royal Australian Regiment Regiment
TFF TTCP	Technology Forecasting and Futures The Technical Cooperation Program
US	United States

1. Introduction

1.1 Background

Technology continues to develop; perhaps one of the few certainties of the modern era and one of its greatest challenges. Defence organisations across the world are increasingly being pressed to employ a range of disparate technologies in new and innovative ways to retain a persistent capability advantage over potential adversaries. Those that embrace and exploit those new technologies in a considered manner are better positioned to adapt and respond to emerging threats, develop superior capabilities, evolve their operating concepts, and shape their force structure.

The Australian Defence Force (ADF) looks to the Defence Science and Technology Organisation (DSTO) to lead the identification and assessment of emerging technologies that offer advantages or represent threats to ADF operations. Biotechnologies have been identified as important because they have the capacity to enhance the performance of combatants on the battlefield across a wide range of tasks and environments. This area of research is perceived to offer enormous potential benefit to Defence yet the obstacles to its practical employment are significant, especially within legal and ethical domains. In order to leverage these technologies, Australia and its partner nations must then be fully informed of the operational benefits that biotechnologies offer to Defence and also legal and ethical limitations to their adoption.

1.2 Program Objectives

Within DSTO, the Technology Forecasting and Futures (TFF) group is a collaborative research facility for the study of emerging and disruptive technologies. It encourages participation and understanding of related issues across academia, government and industry through strategic alliances including bilateral Project Arrangements. TFF then reports to both the Australian and international community, as a centre of excellence for the study of emerging and disruptive technologies. Its objectives are to identify areas of threat and opportunity in developing technologies and to provide technology foresight to policy, strategy and capability development for the Australian Defence Organisation and its strategic partners.

The biotechnology program within the TFF is long standing, established in 2006. Since then the TFF has explored a range of themes in biotechnology through collaboration with centres of excellence in academia.¹ These studies each delivered a comprehensive technology review within their focused field of regard. Particularly in these early studies, the objective was to review the maturity of the technology and to understand the range of potential applications which might be of interest to Defence. More recently, the TFF has

¹ Including Biointegration (Lovell, 2008), Biomimetics (Maddess, 2007; Young, 2008), Biosensing (Gooding, 2006), Genetic Manipulation (Alexander, 2007; Walmsley, 2010), Performance Enhancement (Easteal, 2008; Cocks & Nandagopal, 2013), and Tissue Engineering (McFarland, 2008).

moved on from investigating and reporting about biotechnologies to exploring the implications of biotechnologies and assessing their utility. This marks the next phase of the program, which aims to ascertain if and how biotechnology might be evolved into the future and to determine where that evolution might offer a capability advantage to early adopters.

1.3 Scope

In order to make meaningful insights into the study of biotechnology capabilities it is critically important to understand what these capabilities offer to defence operations. Within the context of the wider biotechnology program of the TFF, this understanding permits us to inform decision-makers and other significant stakeholders about their military benefit and the military effects that can be generated on the battlefield. This report then addresses the following question:

- *Which biotechnologies have the greatest potential to affect the outcome of military operations so that decision-makers have a reasoned assessment of their significance, applicability, and operational value?*

To answer the question, this report presents a robust experimental approach which is applied to assess the impact of biotechnologies on warfighting activities. One specific biotechnology of interest, an intravenous coagulant, has incredible potential to save lives on the battlefield. This technology is assessed through a sophisticated process of modelling and simulation within a case study, which situates it within the military context. This study will lay the foundation for the assessment of a range of technologies beyond coagulants towards other promising biotechnologies; ultimately, providing the TFF with an effective yet practical capability to model and simulate the future of Defence systems.

2. Methodology

2.1 Modelling and Simulation for Technology Assessment

Emerging and disruptive technologies are often difficult and costly to assess. In some instances the technologies are still under development and their specifications may not be fully disclosed. Other technologies may not be able to be openly tested within the legal and regulatory environment of Australia, biotechnologies for example are heavily controlled and for good reason. The simulation of technologies through modelling is often the only practical option available to assess some types of technologies, especially in military operations. Simulation is also generally safer and less expensive than field trials, experimentation, virtual human-in-the-loop activities, and prototyping. The inherent benefits of the approach make modelling and simulation indispensable within Defence and the technique is frequently used as an alternative or complement to qualitative assessment and expert opinion.

Availability of increased computing power at reduced costs provides a readily available increasing resource to analysts. However, even today high-fidelity models consume significant resources and generally cannot be executed in real time. Military operations with Joint services are often being comprised of large numbers of varied actors with varying goals and operating across complex environments. The effects produced in the battle-space are likewise complex in nature having been generated through synergy of effort. Further, the nature of modern combat is often dynamic, of high-tempo, and highly uncertain. In such an environment, operational assessment and evaluation can become problematic due to a need to consider large state spaces, high degrees of non-linearity and interdependence.

Modelling approaches which are amenable to the military context then become of interest. An early landmark in the development and application of these approaches was the Marine Corps Warfighting Laboratories initiative 'Project Albert'. From its inception in 1998, Project Albert employed data-farming techniques, agent-based distillations and supercomputers as a means to understand the landscape of a military problem space (Brandstein, 1998). DSTO analysts participated in the program and the development of a range of agent-based models to a variety of operations analysis problems. It was during Project Albert that the first military Agent-based Distillations (ABDs) were developed.

2.2 Agent-based Distillations in Defence

ABDs are agent-based models that trade sophistication for speed and lower simulation costs. They are so called 'distillations' because of this trade-off, where the distillation encodes and simulates those elements which are considered of greatest impact. Less attention is given to the remaining aspects of the model, having lower interest, and they are modelled at reduced fidelity. As a result simulations tend to be less scripted with less user input than high-fidelity high-cost combat simulation software or seminar war-games. In such models, the emergent behaviour of the system as a whole is considered more important than the behaviour of any single constituent part of the system. This emergent

behaviour is a characteristic of complex adaptive systems resulting from combined low-level interactions between numerous low-level entities in the system. These entities act according to comparatively simple rules but their behaviours combine in synergy to exhibit complex dynamic behaviour (see for example Wheeler (2006)).

Within Defence, a range of agent-based modelling environments have been developed for the analysis of military operations. In New Zealand Defence Technology Agency, the software suite MANA² (Lauren et al, 2001) was developed as an agent-based combat simulator to model and simulate Land forces as a collection of interacting agents. MANA is arguably the most successful agent-based distillation within the Defence arena. However, the software suite ISAAC³ (Ilachinski, 1997) was perhaps the first. ISAAC was developed by the US Center for Naval Analysis and facilitated the exploration of self-organisation and emergence. In Australia, the software suite BactoWars was developed by DSTO as a component of wargaming support to the Australian Army experimentation program (see also Wheeler & White (2008)).

Today, agent-based distillations have become popular within a wide range of application domains and no longer reside solely within Defence. The most popular of these products is Netlogo. Netlogo is a free-to-use agent-based modelling environment developed by Wilensky (1999) at Northwestern Universities Centre for Connected Learning. Its strengths reside in ease of use, flexibility, documentation and community support. Recent versions of the software have also included support for data farming and cluster computation. As a result, it has been the model of choice for hundreds of peer reviewed publications since its release in 1999, across a range of fields, and was also used within Project Albert. The suitability of Netlogo for military applications was explored by Wheeler (2005), who modelled the interaction between civilian populations, guerrilla forces and peacekeeping elements. More recently, Gowlett (2013) additionally explored the use of Netlogo for technology insertion within the historical context of the Falklands War. This work is of particular interest as a leading example of how ABDs can be used to situate emerging technologies within military operations, for the purposes of operational evaluation.

2.3 How Do ABDs Work

ABDs are an analytic technique. At the heart of the technique is the application of computation, to increase the degree of rigor that can be brought to bear on complex problems. To accomplish this task, representation of an event, system, or concept is built into a model and this model is then executed by simulation. The approach is more flexible than say closed form mathematical approaches because the model can be made arbitrarily complex and need not be 'solved' in the traditional sense. Instead, the approach follows a classical experimental methodology, whereby a system is subjected to study and testing. Just like classical experimentation, some of the variables in the model are fixed and others, the variables of regard, are changed in specified ways. During experimentation, the behaviour or response of the system under different stimulus is recorded. A theory or hypothesis about the system can then be tested, typically for statistical strength.

² Map Aware Non-uniform Automata (MANA).

³ Irreducible Semi-Autonomous Adaptive Combat (ISAAC).

There are many different, and equally valid, approaches to developing a representative model for an ABD and establishing the experiment. These depend somewhat on individual preference but more generally it is also true that the broad requirements in implementing different types of models vary considerably. However, in all instances, three inputs are always required of the model:

1. **Specifications of agents** (the actors in the model). A full account of their numbers, capabilities, attributes, properties, functions and performance characteristics.
2. **Description of the environment** (the context in which agents interact). Like agents, characteristics of the environment must also be specified in full.
3. **Statement of behaviours** of all objects, responses to stimuli and environment, and concepts of employment and operation for capabilities.

In the first instance, specification of physical characteristics associated with known technologies and capabilities is a comparatively straightforward task. This step defines the agents or actors in the model. Technical details of platforms, sensors, weapons and other systems can be defined in quantifiable terms and translated into the model, as appropriate, for the task at hand. Where the systems to be tested are still in development, prototype, or otherwise untested, then performance characteristics might instead be estimated.

Modelling of an environment and wider strategic context is a slightly more complex task. The key components of a well-developed scenario, for military applications suiting our purpose, are adopted from Wheeler (2010). While the strategic context in a military scenario is typically not used for purposes of modelling, each of the other three categories (environment, participants, and sequencing) are immediately useful. As an additional benefit, it is also convenient to follow this standard template when developing models of defence operations to because it is easily recognisable by a military audience.

Table 1: Definition of a military scenario

Broad Category	Particular Product
Context	Strategic Narrative
	National Intent
	Military Objectives
Environment	Weather
	Terrain
Actors	Concept of Operations
	Command and Control
	Rules of Engagement
	Order of Battle
Sequencing	Chronology of the Battle
	Lines of Operation
	Phasing / Vignettes

The behaviour of each entity in the system must be appropriately defined for input to the model. Entities and objects have internalised behaviours, which might be carried out in the absence of opposition. Agents for example might have concepts of employment and operation. Entities also possess tailored responses. These might be carried out as a result of pressure, from external stimuli and the environment.

In contrast to the physical properties of a system; the behaviours of a system, entity, object or organism are difficult to describe. The specific implementation of behaviours can be ambiguous and open to subjective interpretation.⁴ The primary means to overcome subjectivity in depicting agent behaviour is to undergo historical benchmarking. In a historical model, the behaviours of all agents are well documented and cannot be disputed. This corresponds to a representation of the 'Sequencing' component of the scenario description, where the actions of all participants are known.

2.4 Historical Case Study for Technology Assessment

Once all aspects of the model are defined, experimentation can be conducted through process of simulation. This paper will analyse how military operations are affected by the employment of emerging and disruptive technologies in those simulations. In particular, we model the impact that intravenous coagulants have on the battlefield.

A key component of this work is the representation of appropriate military scenarios. This is essential because the validity of the model is established by accurately reproducing the historically documented operational dynamics and outcomes. There are three phases to the implementation of this approach:

1. Benchmarking and verification using historical case studies in a single ABD.

In this study, the Battle of Long Tan, Vietnam 18 August 1966, is used to baseline the model. This scenario is appropriate because the conflict is well documented, meaning that the model can be finely calibrated. The model then contains a detailed timeline of scripted events and a representation of the capabilities, behaviours and force elements which took part in the battle. This is important because it is used to accurately recreate the encounters which took place on that day and their outcomes.

⁴ Not all applications directly require, or otherwise depend on, complex and subjective behavioural rules. Applications include the spread of disease and contagion, study of natural disasters including wildfires and floods, contamination effects of CBRN reagents, emergency response situational studies, and riot control and crowd dynamics. In such situations, the aggregate behaviours of the participating entities are well understood and are not subjective.

2. Development of a second model in a different ABD for independent external authentication of results.

Modelling the Battle of Long Tan allows us to assess operational effectiveness and operational risk. The historical outcome of the battle is known. The next step is to compare how that outcome is affected by the insertion of new technologies which were not a part of the original conflict. These technologies offer the forces a capability enhancement and the impact of the enhancement can be measured through quantitative metrics developed and customised for that task. It is also recommended that a second ABD in a different software suite is developed simultaneously with the Netlogo model. Using multiple, independent models ensures that implementations are consistent and that outcomes are reproducible.

3. Application of both models to selected case studies of interest to predict the impact of biotechnologies in current and future combat.

This approach allows us to determine how biotechnologies provide capability enhancements, such that the change in capability is significant in operations. Key to the application of the methodology is the development of the credible and controlled environment where the model is benchmarked against historical precedent. Nevertheless, it is not sufficient to simply take a single case study as a generalisation of the impact biotechnology has across the range of all potential battles. It is also of limited utility to examine the impact of biotechnology in historical combat alone because the reason we are developing these models is to employ them in a predictive sense. The objective of this program of work is to determine the impact of biotechnology in both current and future contexts.

Within the scope of this study only the first phase of the methodology will be reported in this paper. The battle of Long Tan will be used as the historical case study and the software suite Netlogo will be employed as the ABD. The second and third phases of the program will be conducted at a classified level and will not be documented within this report.

3. Modelling Conflict at Long Tan

An extended account of the battle was developed for this study by BRIG (ret.) Justin Kelly; a retired Australian Army officer with extensive experience in land warfare, having been the Director General of the Future Land Warfare branch at Army Headquarters and the Commander of the Australian Land Warfare Development Centre. This account is provided in full within Appendix C, D and E. Section 3 provides summary information taken from BRIG Kelly's account.

3.1 Battle of Long Tan

The Battle of Long Tan took place during the Vietnam War near Phuoc Tuy Province on 18 August 1966. It was fought between the Australian Delta (D) Company, of the 6 Battalion Royal Australian Regiment (RAR), and Viet Cong forces of the 275 Regiment, 5 Division. Local forces of D445 Provincial Mobile Battalion, which normally operated to the south of the province, also participated.

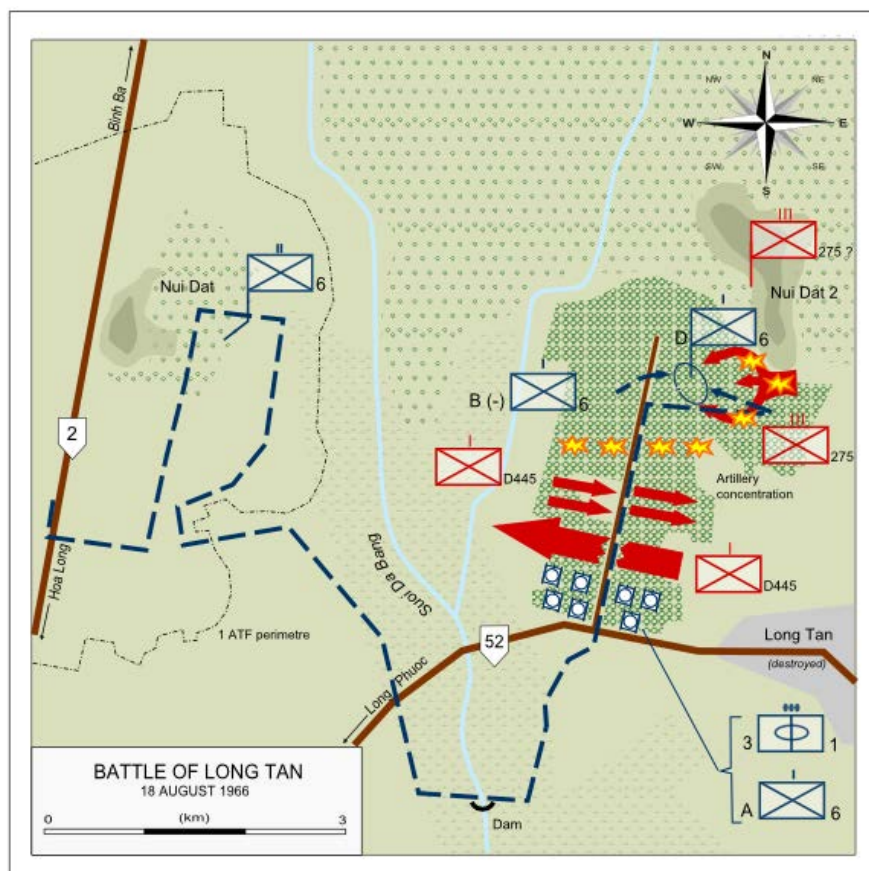


Figure 1: Battle of Long Tan⁵

⁵ Creative Commons Attribution Share Alike 3.0 Unported license. Filename: Battle_of_long_tan_18_August_1966. Attributed to: Anotherclown at English Wikipedia.

Operation 'Vendetta' began at 15:00, as D Company executed a search-and-destroy mission in the contested area to the east of the Australian Task Force base at Nui Dat. First contact was made at 15:42 with a small Viet Cong scouting party. Wishing to push the advantage the Australians followed with speed and aggression, which dangerously extended their company formation.

Unfortunately for D Company, the Australian advance was met by the numerically superior Viet Cong force outnumbering the Australians by more than 20 to 1. The forward platoon (11 Platoon) was attacked on three fronts and almost isolated. Finally, at 17:50, 11 Platoon was able to retreat under cover of artillery fire, leaving behind almost half its men unaccounted and with heavy casualties. Upon reconstitution with the other platoons, D Company mounted a perimeter defence to repulse the enemy attack. At 18:40, after three long hours of combat, D Company was reinforced by an emergency relief effort from Nui Dat and the enemy withdrew from the field.

At the end of the battle, 18 Australians had been killed (one from the relief force) and 21 wounded. Against the odds and with considerable heroism, the Australian infantry survived and in so doing created the opportunity for the Australian artillery to dominate the battlefield. The Viet Cong had suffered a decisive defeat, with an estimated 500 dead and 1000 wounded, and never again mounted any significant challenge to Australian forces at Nui Dat.

3.2 Environment

The engagement occurred within the Long Tan rubber plantation. The plantation was flat, offering little natural cover. However, the density of the vegetation hampered visibility, reducing it to approximately 150 meters. An average infantry patrol can manoeuvre at rates well exceeding 1.0 ms^{-1} . However, on the day the rate of advance covered approximately 800 m to 1000 m over the first 30 minutes of the patrol. This is probably indicative of combat operations during a search and destroy mission, where there is both uncertainty of enemy position and a large area to be covered.

Table 2: Agent Visibility and Movement

	Visibility	Movement
Before 16:20	150 m	0.5 ms^{-1} (max)
After 16:20	50 m	0.65 ms^{-1} (max)

Around 16:20, a monsoon torrential downfall ensued reducing visibility to 50 metres and liquefying the field. Ground conditions impeded movement significantly and a red mud mist rose as high as 50 cm under the intensity of the rain. This obscured sight of, and provided cover to, any person who was lying prone. Nearer the end of the engagement, when 10 and 12 Platoon were withdrawing, their retreat was conducted at a faster rate, covering approximately 400 m in 10 minutes.

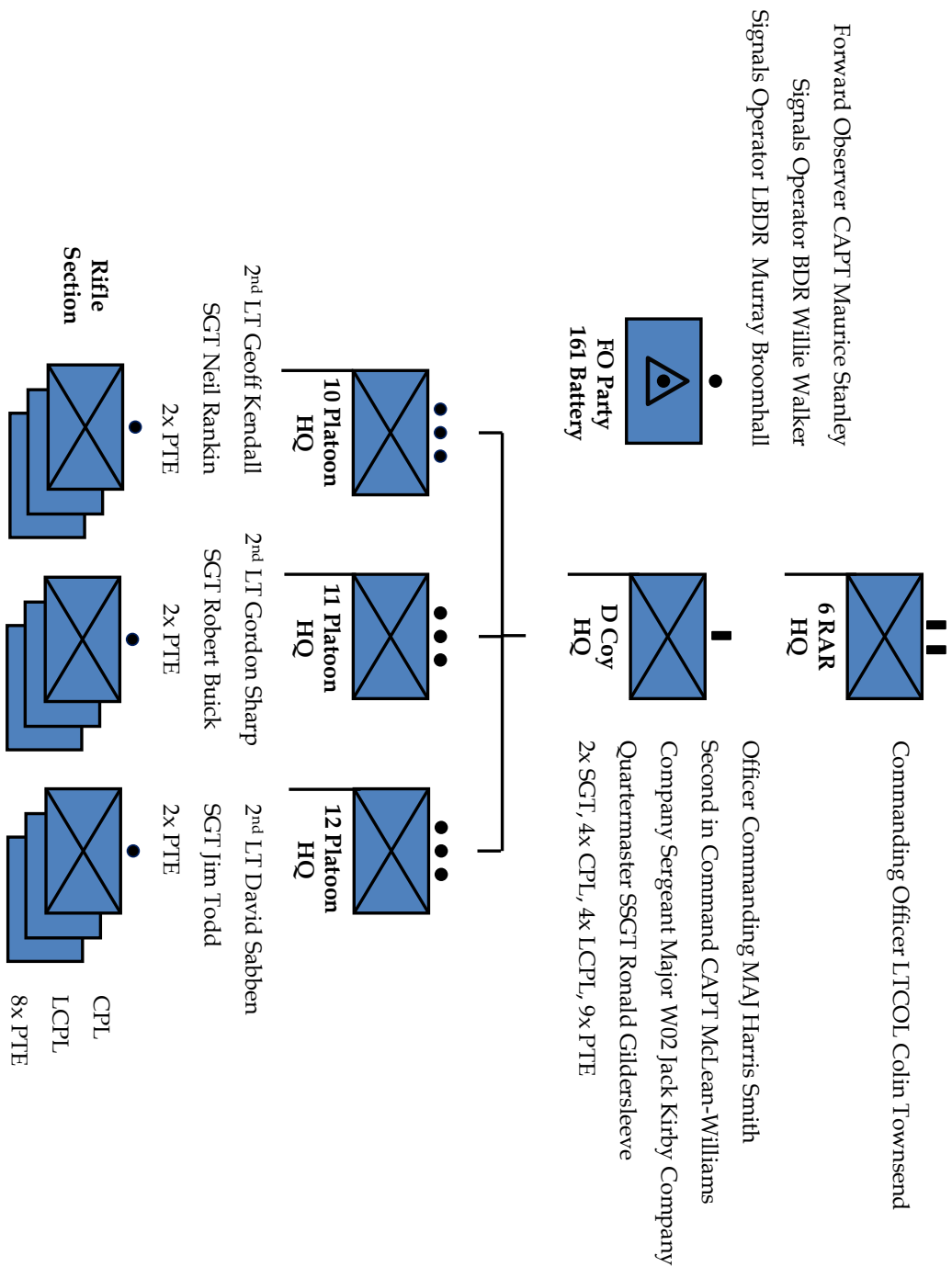


Figure 2: D Company Order of Battle

3.3 Australian Agents

D Company, 6 RAR, or D/6, consisted of three Australian infantry platoons numbered 10, 11, and 12, a Company Headquarters (Coy HQ) and a Forward Observer (FO) party of 3 NZ artillerymen from 161 Battery. Each Platoon was organised into a platoon HQ of four commanded by a 2nd Lieutenant, and three rifle sections of 10 infantrymen (see Figure 2).

Only 105 Australians from 6 RAR and the 3 Royal NZ artillerymen participated in the battle. Each of 11 Platoon's three sections (numbered 4, 5, and 6) were reduced to 8 men at the time. However, the specific operational size of 10 Platoon, 12 Platoon and Company Headquarters is not recorded.

Table 3: Agent numbers and formations (Australian D Company)

	Number of Agents
D Company HQ	17 + 3 RNZA
10 Platoon	30
11 Platoon	28
12 Platoon	30

At a minimum, company headquarters would have been staffed by the senior personnel (as named) and a Company Mortar Fire Controller, as well as medics, signals (radio) operators and messengers. We conclude then that each of the rifle sections in 10 and 12 platoons were on average at least one man short of full complement.

3.4 Australian Equipment

Australia infantrymen carried either the L1A1 Self-loading Rifle or M16 Assault Rifle, depending on rank and role. Standard loading was 3 magazines each containing 20 rounds with 60 rounds in pack. Additionally, a three man team within each rifle section was equipped with the M60 General Purpose Machine Gun and 10 belts of 100 rounds. Both the L1A1 and M60 were heavy 7.62 mm rounds, which was able to maintain effectiveness even in the rain and foliage. The M60 was slightly less accurate but was capable of sustaining a greater incidence of continuous fire with its larger belt capacity.

The M16 fires a 5.56 mm round and was an inferior weapon on the day due to its reduced lethality firing through rubber trees. However, less than 10% of personnel carried this weapon. Estimates for the accuracy of 5.56 mm and 7.62 mm weapons vary, although the dispersion characteristics of many military small-arms are well documented (see Kjellgren (1970)). Some studies report a 1 in 2 ratio for wounding on an aimed shot, others as much as 1 in 20 in combat situations. Contrary to popular belief, rainfall will not significantly deviate the trajectory of a 7.62 mm round and winds of 2 ms⁻¹ would impose a deviation of less than 2 cm over 100m. The main determining factor in this engagement is low visibility, reduced light and deflection from shooting through the rubber trees themselves. Exchanges occurred at about 50 m, which was the maximum visible range at the day after 16:20.

Table 4: Probability of agent wounding an enemy (independent per round expended)

% Hit	Rifle / Gun	Artillery ⁶
Before 16:20	1 in 15	N/A
After 16:20	1 in 30	1 in 3

Other than the initial skirmishes (up to 16:00), the Australian forces of 11 Platoon deployed their fire in a defensive capacity and two UH-1B Iroquois from 9 Squadron RAAF resupplied D company shortly after 18:00 as ammunition ran critically short. The battle lasted only 3.5 hours so that on average each rifleman could not reasonably have expended more than two rounds a minute on average and more likely less. Rounds would actually be exhausted in short bursts, committed to engaging a target, of perhaps three rounds. As the Australians formed a defensive line, the majority of fire was from a sieged position where neither force was able to exert a significant advantage over the other. From a sieged position, Australian riflemen conserved their rounds, taking the occasional aimed shot of opportunity, and the M60 was employed to suppress the enemy position intermittently as required.⁷

Table 5: Ammunition usage by agent when engaging an enemy

	Rifle	Artillery
Under Siege (at 50m)	1 rpm (average)	1 rpm (sustained)

The majority of enemy fatalities were inflicted by artillery support stationed at Nui Dat. All 18 of the Australian and New Zealand L5 Pack Howitzers fired almost non-stop. Planning data for the Australian L5 Pack Howitzer reports a theoretical 2 rpm sustained action. However, the ammunition expended on the day indicated only 1 rpm was achieved. During the peak of the battle an additional battery of 6 US M109 Self-propelled Howitzers were also called to support the effort and the total number of artillery rounds expended exceeded 3,500. Suppression fires were brought in 'Danger Close' to the Australian position to a distance of 50 meters around 17:00. As a result, Viet Cong maneuvering around the company were subjected to a lethal band of continuous artillery fire several hundred meters in depth.

⁶ Greater than 60% of all fragmentation wounds are not critically serious (death within 6h). According to Champion et al (2003) only 5 to 7 fragmentation wounds might on average result in life threatening trauma. However an artillery round has a large radius of effect. Given infantry dispersal of between 5 and 10 meters per man, fragments would strike multiple personnel. This number of 1 in 2 should then be considered indicative of this particular battle and only then as a working estimate. In any case, we do not attempt to model wounding in Viet Cong forces and artillery was only employed by the Australian side.

⁷ Although the conflict was intense, overheating could not have been a problem, which would normally occur at a sustained usage rate of 12 rpm. The barrel on the M60 can also be changed but even then the rate of fire is limited to 100 rpm with a 10 minute barrel exchange or 200 rpm with a 2-5 minute barrel exchange.

Approximately 500 Viet Cong were killed over the course of the engagement and more than 1,000 wounded. As a result of the reduced visibility during the Monsoon and the suppression fires, Viet Cong casualties below about 50-75 metres were nearly all inflicted by small arms fires (gunshot) and artillery rounds accounted for almost all casualties past that range. A US airstrike and Viet Cong mortar attack were both misplaced, neither inflicting casualties.

3.5 Viet Cong Agents

Planning and control of the Viet Cong operation was the responsibility of HQ 5 Division, whose responsibilities included Phuoc Tuy. HQ 5 Division commanded two regiments numbered 274 and 275. Only the latter was directly involved in the battle. Provincial Mobile Battalion D445 was also under command.

The 275th Main Force Regiment was made up of full-time fighters based in the May Taos and mainly operated in the east of the province. They wore the pith helmet and green uniforms common to the North Vietnamese Army, carried the same weapons, and could operate in battalion or regimental strengths. Commanded by Senior Captain Nguyen Thoi Bung, it consisted of three battalions—H421, H422 and H423⁸—and a regimental headquarters with a total of 1,850 men. Each battalion consisted of a battalion HQ, three rifle companies and a heavy weapons company.

Table 6: Agent numbers and formation (Viet Cong 275 Regt)

	Number of Agents
275 Regt HQ	350
H421 Btn	500
H422 Btn	500
H423 Btn	500

In addition to its infantry battalions the 275 Regimental HQ had under its command a 82 mm mortar company, a 12.7 mm heavy machine gun company and an anti-tank company, as well as communications, transport, medical and engineering support.

⁸ Recomposing NVA D605 Battalion.

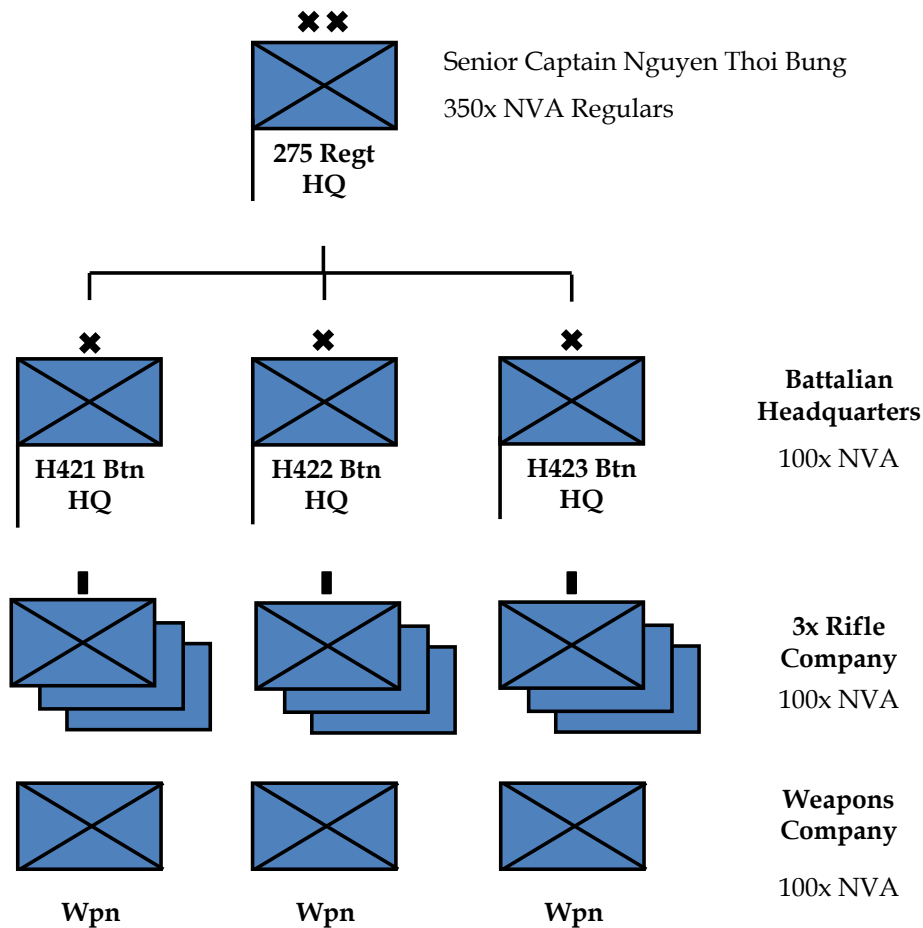


Figure 3: 275 Regiment Order of Battle

D445 Battalion was a regional force battalion comprised of four companies of full-time soldiers. Regional Force units normally served within or close to their home provinces and D445 Battalion normally operated in the south of the province and in Long Khanh. They were not as well armed as the main force and usually operated as small units that seldom exceeded company strength. D445 probably numbered at 550 men, under the command of Bui Quang Chanh, and was comprised of three rifle companies – C1, C2, and C3 – and a weapons company C4. It seems likely that only C1 and C2, and some elements of the C4, were engaged at Long Tan.

Table 7: Agent numbers and formation (Viet Cong D445 Battalion)

	Number of Agents
D445 Btn HQ	80
C1 Coy	120
C2 Coy	120
C4 Coy	120

D445 Battalion largely participated in flanking manoeuvres to the South of D Company and skirmishes with the Australian relief force from 3 Troop of 1 APC Squadron, A Company and the Headquarters from B Company. Hence, D445 was not directly involved in the Viet Cong main effort.

3.6 Viet Cong Equipment

The Viet Cong infantry were equipped with the 7.62 mm AK-47 Assault Rifle. It was a reliable weapon but somewhat prone to inaccuracy when fired in fully automatic mode. Its magazine is slightly larger than the Australian's L1A1 and carried 30 rounds. The 7.62 Soviet RPD was the Viet Cong light machine gun. Like the Australian's M60, it was also fed by a belt of 100 rounds. However, it was somewhat more reliable than the M60 as the feed system was encased inside a drum magazine which protected it against dirt, moisture and stretching of the belt which were problems experienced with the M60.

There no reason to believe that the Viet Cong would employ their AK-47 substantially differently than the Australian's employed their L1A1 or M16. Further, the RPD is a similar system to the M60. To the extent of this model, we assume the same limitations on rate of fire and accuracy (although the Viet Cong were not as well trained). We do not model Viet Cong artillery, as this was not brought to bear on the forces within the Long Tan rubber plantation, but only against the Australian Task Force Headquarters at Nui Dat.

There is one obvious discrepancy between the behaviors of the Viet Cong forces and the Australian. The Australians largely fought under siege where personnel sought to defend their lines and engage the enemy from cover. However, the Viet Cong forces mounted forced assaults against the Australian position seeking to overwhelm it. During those assaults, the Vietnamese personnel would be moving towards the Australian line while under suppression of artillery and an entrenched machine gun position.

Table 8: Probability of agent wounding an enemy (during an assault)

% Hit	Rifle / Gun	Artillery
In Assault	Not Used	Not Used
Supporting	1 in 30	Not Used

It is unreasonable to assume that the Viet Cong could bring accurate fire to bear on the grounded Australian line during a forced charge and the Australian line was never breached. Hence, during such assaults, the probability of a Viet Cong soldier wounding an Australian is significantly degraded. The specific number of such assaults is not known, only the broad scheme of maneuver. It is also evident that the Viet Cong were unable to mount an effective assault due to positioning of the Australian formation, which prevented flanking. The devastating effect of artillery also prevented the enemy from massing forces and seemingly no more than two enemy platoons were ever able to apply pressure on the forward Australian position simultaneously. We assume that each charge was conducted by only one platoon, the other providing covering fire from a support position.

3.7 Lines of Operation

Operation Vendetta began at approximately noon on the 18th August 1966 with a 'one-up' company formation (see Appendix H). However, shortly after a 'two-up' formation was adopted in order to follow two tracks, both leading East. No contact occurred until 15:40 when 11 Platoon (southern-most element) encountered a Viet Cong section of 8 men.

Table 9: Sequence of decisive events simulated in the model

Time	Event
15:40	Contact Report by 11 Pl Enemy Section retreats to the East
16:00	Fast Pursuit by 11 Pl Opens 200 m distance to rest of Company
16:10	Contact Report by 11 Pl Platoon under heavy fire from 275 Regt
16:15	Captain Morrie Stanley calls in 161 Battery 10 Pl moves to support withdrawal of 11 Pl 12 Pl assigned to defend Coy HQ
16:20	Contact Report by 10 Pl Encounters forward elements from 275 Regt Remaining 1 Field Regt artillery called in
17:00	Two Sections of 12 Pl sent to support 10 Pl withdraws to Coy HQ VC breach 50m line to 11 Pl
17:20	Contact Report by 12 Pl (forward Sections) Encounter flanking elements from 275 Regt
17:50	11 Pl abandons position Leaving 15 MIA and joining 12 Pl
18:10	Ammunition Drop Company HQ is attacked by 275 Regt
18:20	10 Pl and 12 Pl reach Company HQ Heavy assault from Viet Cong
19:00	Reserve force arrives Viet Cong abandon the field
23:00	Casualties Evacuated (1 DoW) 15 MIA remain on the field
11:00 (D+1)	MIA recovered Total Casualties 18 KiA and 24 WiA

In the initial engagement Sergeant Bob Buick expended two rounds, wounding one of the enemy. It is at this time 15:40 that we start our model. Table 9 outlines the sequence of decisive events from this point. A detailed line of operations is also provided in Appendix E.

4. Modelling Casualty Statistics at Long Tan

4.1 The Case for Haemostatic Biotechnologies

Penetrating wounds are the most common injury incurred in combat, resulting from both gunshot and shell fragmentation (see also Appendix G). In Vietnam this accounted for approximately 96% of all wounds (see Table 11). Furthermore, approximately 50% of fatalities from a penetrating wound are attributed to blood loss (Champion et al, 2003).⁹ The remaining 50% are attributed to a number of different causes including: trauma to the central nervous system, laceration of the heart, spinal damage, comminuted fracture, respiratory failure and trauma as a result of amputation. Over a longer duration untreated sepsis, pleural empyema, peritonitis and ischemia are primary causes of death. See Bellamy (1984).

Table 10: Injury type as a result of penetrating wound

	Haemorrhage	CNC Trauma	Other Causes
Probability	50%	30%	20%

Blood loss, or haemorrhage, is often treatable and a large number of casualties bleed to death on the battlefield because of lack of first aid.¹⁰ Of those that do die of haemorrhage, 80% of their wounds are to the torso where blood loss cannot easily be controlled.

Table 11: Wound distribution in selected engagements (Sakorafas & Peros, 2008)

Engagement	Gunshot	Fragment	Other
World War I	39	61	-
World War II	10	85	5
Korea	7	92	1
Vietnam	52	44	4
Borneo	90	9	1
Afghan War (Russian)	23	68	9
Gulf War	11	88	1
Operation Iraqi Freedom	39	31	30

Bellamy (1984) additionally, observes that approximately 38% of fatalities who died of haemorrhage in Vietnam were treatable (at least temporarily) by simple first aid.

⁹ Champion et al (2003) analysed records of almost 8,000 patients between 1967 and 1969.

¹⁰ Casualty evacuation statistics for Vietnam are even more compelling, where greater than 87% of evacuates recorded to be bleeding as a result of treatable arterial wounds.

4.2 Mortality Rates in the Vietnam War

In theatre, Combat Health Support (CHS) provides care to personnel including: casualty evacuation; treatment and hospitalisation; provision of medical logistics; and preventative health services. By the Vietnam War, CHS had significantly developed.¹¹ Combat first aid (assisted and self-applied) was carried out promptly wherever possible. First aid could be provided by non-medical personnel with a focus on maintaining respiration and controlling life-threatening bleeding.

Across both military and civilian practice, recovery is improved if first aid can be provided as soon as possible. The so called 'Golden Hour' (Lerner & Moscati, 2001) originally described a window of opportunity within which to treat serious trauma or uncontrolled bleeding. Today, it is not regarded as depicting a fixed window of 60 minutes but more generally describes the urgency to treat severe trauma as quickly as possible.

Table 12: Predicted mortality rates in untreated combat casualties (Bellamy, 1984)

Location of Wounding		Probability of Mortality (%)				
Location	%	0 - 1 hr	1 - 6 hrs	6 - 24 hrs	1 - 7 days	Total
Head	14.0	50.0	7.9	10.7	19.3	87.9
Face	7.0	8.6	2.9	1.4	34.3	47.1
Neck	2.5	36.0	8.0	4.0	12.0	60.0
Thorax	12.5	38.4	8.8	6.4	26.4	80.0
Abdomen	10.0	28.0	17.0	16.0	31.0	92.0
Upper Limb	20.0	2.0	2.0	1.5	14.5	20.0
Lower Limb	31.0	4.8	3.9	3.2	21.6	33.5
Multiple	3.0	50.0	23.3	10.0	16.7	100.0

Modern medical guidelines for combat care focus on the 'platinum 10 minutes' (Miles, 2013) as being critically important, with a time to surgery of 2 hours following wounding. Aero-medical evacuation by rotary-wing aircraft is the preferred means of combat evacuation because of the ability to extract casualties quickly from remote and inaccessible areas (see also Appendix F).

In Vietnam, 1-hour was considered a rapid evacuation. Soldiers would generally not be evacuated before 6-hours and in less severe cases 24-hours or more. Following Bellamy's model, 19.5% of casualties in Vietnam died before rapid evacuation was complete. An additional 2% of casualties then died of wounds. This number increases to 4% dying of wounds with 6-hour evacuation delay and 8% after 24-hours. However, it is noted that mortality rates vary considerably with weather and in extreme conditions.

¹¹ "In the Vietnam War wound management included infusion of patient with Ringer's Lactate [an intravenous medical fluid replacement with a similar usage to saline solution] and antibiotics, with debridement [the surgical removal of damaged or infected tissue] of the wound and open packing with occlusive [providing an air and water tight seal] dressings. Secondary closure was unusually achieved within seven days." (Taylor & Jeffery, 2009).

4.3 Effect of Blood Loss on Personnel

Even today, the most common cause of death on the battlefield is blood loss. The average adult male (70 kg) contains about 5 litres of blood and can sustain a loss of about 500 mL of blood without experiencing significant duress (Cropp, 1971). The American College of Surgeons (1997) provides the following table to describe the four classes of shock.

Table 13: Classes of haemorrhagic shock

	Class I	Class II	Class III	Class IV
Blood Loss (mL)	< 750	750 - 1500	1500 - 2000	> 2000
Blood Loss (%)	< 15%	15 - 30%	30 - 40%	> 40%
Pulse Rate (bpm)	100-	100+	120+	140+
Blood Pressure	Normal	Normal	Decreased	Decreased
Skin Condition	Normal	Cool Mottled	Cool Pallor	Cold Cyanosis
Respiratory Rate (bpm)	14 - 20	20 - 30	30 - 40	35+
CNS & Mental Response	Anxious	Irritable Combative	Lethargic Confused	Coma
Pain Response	Normal	Normal	Reduced	Reduced

Symptoms of shock begin to develop after losing about 15% of blood volume. A healthy human body will attempt to control additional loss through lowered blood pressure, normally within 10 minutes. However, if the injury sustained affects arteries or major blood vessels then external aid will be required to prevent mortality.

4.4 Treatment and New Technologies

In our simulation, wound profiles are generated according to Table 10 and Table 12. The location of the wound is randomly generated according to these statistics and 50% of all wounds result in haemorrhagic shock if not treated. Based on a 5 litre capacity of blood and the probability of mortality within each of the timeframes, the average rate of blood loss can be calculated.¹² These wounds are treatable if blood loss can be controlled sufficiently quickly. This also implies that the remaining 50% of wounds are not treatable, at least not by the haemostatic biotechnologies we seek to model.

Blood infusion becomes critical in the treatment of those wounds because fluid replacement is often the only way to stabilise a haemorrhaging soldier. However, this procedure is not generally available until casualty evacuation. Thus, our focus is on technologies which reduce or restrict blood loss with the aim to extend a soldiers life until casualty evacuation can be completed. One of these future technologies is the development intravenous haemostatic nanoparticles, which work by bonding blood platelets with blood cells to encourage clotting (see Bertram et al, 2009; Ilinskaya & Dobrovolskaia, 2013). A

¹² This is used to establish a stopwatch or timer in our model which denotes the time until death for each casualty. The timer does not accurately measure the true volume of blood lost over time because the rate of blood loss is not linear. However, the average rate is sufficient for our purposes.

recent study by researchers at Case Western Reserve University, Wayne State University and Virginia Polytechnic Institute has demonstrated a 30%-40% improvement in survival rate within laboratory mice in a 1-hour timespan (Lashof-Sullivan et al, 2014). In their study bleeding was reduced by approximately 50%.

Intravenous treatment using nanoparticles has yet to be approved for human use. However, there are a wide range of treated combat gauzes in current use with varying efficacy (Arnaud et al, 2009). The current generation of gauze used by the US military (QuikClot) is impregnated with Kaolin which encourages clotting in the area of contact. Previous generations also included chemicals to absorb moisture, some of which were exothermic (generating a localized cauterization). Alternatively, Fibrin bandages contain fibrinogen and thrombin which combine with blood to form a fibrin seal. This product can be left inside the body and will naturally biodegrade meaning it has advantages when used in surgical operations. However, contact treatments are comparatively ineffective in torso wounds where bandaging is not sufficient to control the bleeding. This is one of the advantages of injected treatments which are also able to treat blast injuries and internal trauma, a significant improvement over other technologies which can only be applied for localised external treatment.

Table 14: Reduction in (average) bleeding rate after receiving medical treatment

	Self Treated	Company Medic	Intravenous Nanoparticles
Reduction	15%	30%	50%

Ideally, we would like to produce a new version of Table 12 to incorporate different outcomes for each specific type of wound after treatment and for each type of technology. However, this is not possible. In the absence of this information, Table 14 is then a first-order model where reduction in bleeding applies only to the average rate of bleeding. This can be interpreted as extending the casualties life by $2500(1-r)/rb$ minutes; where, 2500 ml is the volume of blood loss resulting in death, r is the proportion reduction during treatment, and b is the original average rate of bleeding.¹³

We assume that any soldier who is not undergoing a Class III or Class IV haemorrhage is able to treat his own wound. We further assume that any platoon within range of a company medic is able to receive combat aid in the form of a standard military dressing. The benefit of Self Treatment and the Company Medic are not cumulative (medic taking priority). Finally, we compare this historical model against one in which all personnel are supplied with an intravenous coagulant. This treatment is automatically applied to individuals during a Class III (or worse) haemorrhage. This benefit is cumulative and will be applied on top of any other treatment.

¹³ This equation describes a fixed case where the casualty received only one type of treatment, treatment is immediate, and treatment is continued until death or medical evacuation. Treatment is applied at a 1 minute resolution within the model. During simulation, casualties may for example treat their own wound until reaching a company medic. Extension of life in that instance occurs at a pro rata basis.

5. Operational Assessment of Haemostatic Biotechnologies

5.1 Empirical Results

In this section we conduct the number $N = 5000$ independent executions of the model. The core Netlogo routines are provided in Appendix I and a screenshot of the model in Appendix J. At the end of each execution, Australian casualties are classed as either:

Table 15: Classes of casualties

Statistic	Definition
<i>Killed-in-Action (KIA)</i>	Mortality prior to medical evacuation.
<i>Wounded-in-Action (WIA)</i>	Wounding requiring treatment within 7-days.
<i>Injured-in-Action (IIA)</i>	Wounding not requiring treatment.

We do not record personnel who *Died-of-Wounds* (DoW) during evacuation or while under care at a medical facility. Estimates for this value are provided at the end of Section 4.2. For the sake of completeness, only one Australian soldier Died-of-Wounds during the Battle of Long Tan; PTE AF McCormack, a 21 year old serviceman from Launceston.

For brevity, raw simulation results are not provided in this report. The sample means and corresponding standard deviation for each of the three statistics are provided in Table 16. This table documents the results from the control group, in which only self-treatment and company medics are able to treat casualties.

Table 16: Sample results (baseline group - without intravenous injection)¹⁴

Statistic	Sample Mean	Standard Dev.
<i>KIA</i>	19.37	3.58
<i>WIA</i>	15.59	3.56
<i>IIA</i>	16.61	3.83

Of particular note here is the total IIA. This describes the total number of personnel who received wounds not requiring treatment. There are two points of note. First, it is not entirely clear at what point a 'wound' becomes reportable as such. In reality, many soldiers who received minor injuries would still have sought treatment. Second, Champion et al (2003) notes that 62% of wounds in Vietnam were inflicted by fragmentation. The model of wounding we use, developed by Bellamy (1984), also encompasses both forms of ballistic wounds, bullet and fragmentation. However, during the Battle of Long Tan the Viet Cong did not employ artillery against Delta Company and their mortar strikes were ineffective. Since the average fragmentation wound is less lethal

¹⁴ VC casualty data is not analysed. However, for completeness the mean number of VC KiA in the sample results was 439.02 with a standard deviation of 20.05. The mean number of VC WiA in the sample results was 878.08 with a standard deviation of 26.87. VC IiA are not recorded.

than the average bullet wound, the predicted incidence of injuries would be greater in our simulation results than that which actually occurred during the battle. However, this observation is largely immaterial to the study as we are only concerned with prolonging soldiers' lives until medical evacuation can be completed. Thus, our primary statistic of regard is then the number of personnel KIA. A histogram of this statistic is presented in Figure 4. This is provided for illustrative purposes only, for those wishing to visualise the results. No other analysis is conducted on this diagram.

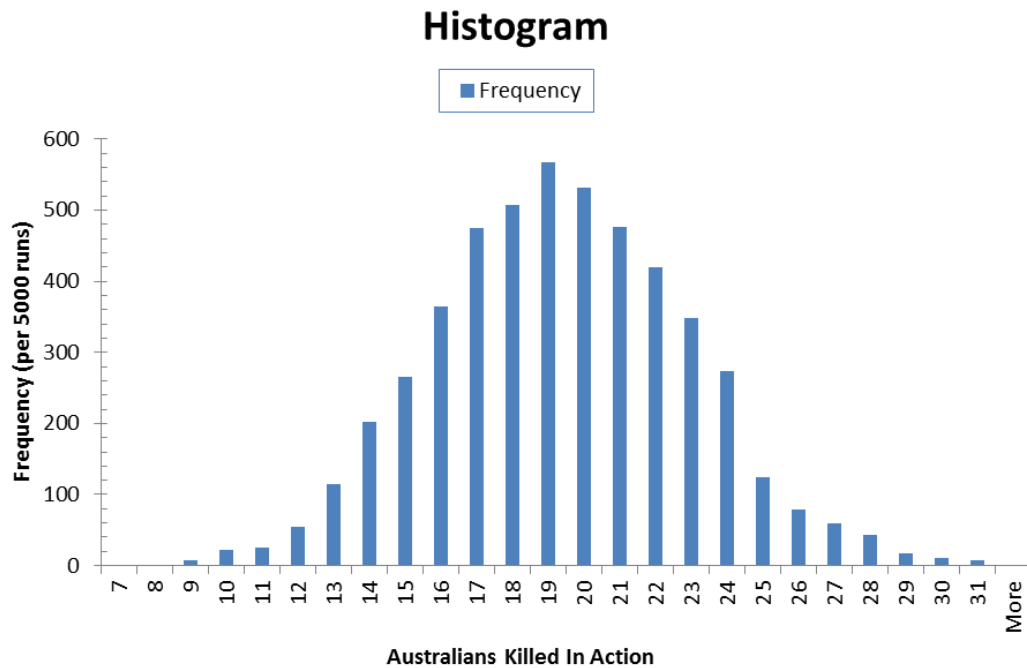


Figure 4: Histogram of Australians KIA

A second set of N simulations was conducted. This table documents the results from the experimental group. In this set, intravenous injection of haemostatic nanoparticles was also used to treat casualties, with efficacy as per Table 14. A histogram of the dataset is not presented because it appears (visibly) almost identical to the baseline. Statistical testing will be used to determine the significance between the two datasets.

Table 17: Sample results (experimental group - with intravenous injection)

Statistic	Sample Mean	Standard Dev.
KIA'	18.76	3.62
WIA'	16.13	3.64
IIA'	16.62	3.85

The reduction in personnel KIA is approximately 3.5% with intravenous injection. While this may appear small, only 50% of all deaths were a result of haemorrhagic shock. In that

sense, we conclude that the treatment has in fact fully saved the lives of 7% of personnel, of those that could have been saved in this way.

An alternative way to look at this outcome is to ask how long casualty evacuation could be delayed, on average, for the same number of fatalities. Running a course parametric search (accurate to the hour) the mean number of deaths in the control group at 11:00pm is approximately equal to the mean number of deaths in the test group at 1:00am the following day. This indicates that the haemostatic nanoparticles, on average, extend the time-window for casualty evacuation by as much as 2 hours. Of course, this is only meaningful to casualties where bleeding is the primary cause of death and is an irrelevant observation applied to all other forms of wounds.

Some assumptions have been made within the model, the injection is only administered to patients during Class II haemorrhage (15% blood loss by volume) or greater. A 15% loss of blood is not itself life threatening but it is a significant amount. The average lifespan of casualties could be increased even further if the injection was administered earlier. Further, personnel who DoW (after medical evacuation) have not been recorded in our model. It might be reasonably assumed that mortality can also be reduced here. This could be tested on larger sample sets, as only one infantryman DoW in the Battle of Long Tan. As a final point, Section 4.4 briefly discusses modern forms of bandages. Today, treatment using say QuikClot Gauze or an equivalent is more effective than predicted in Table 14 for historical bandaging (refer to Arnaud et al, 2009).

5.2 Statistical Significance

Let μ_K , μ_W , and μ_I , denote the true mean statistics for those KIA, WIA and IIA respectively. Further, let μ_K' , μ_W' , and μ_I' denote their counterpart statistics KIA', WIA' and IIA'. Then, we pose the:

$$\begin{aligned} \text{Null hypothesis to be } H_0: \mu_K &= \mu_K' \\ \text{Alternative hypothesis to be } H_a: \mu_K &\neq \mu_K' \end{aligned}$$

It is not meaningful to examine the number of soldiers WIA because this statistic is confounded with the number of soldiers KIA in that the total *expected* number of soldiers KIA, WIA and IIA is the same for any simulation, irrespective of the effectiveness of any treatment applied. This does not mean to say that there is no variation between each independent trial but that the expected amount of WIA + KIA + IIA will not change. This is a direct reflection of the probability of wounding and the distribution of wounds (which are fixed). Hence, on average we know the number of personnel actually being wounded must be the same but the distribution of those personnel into each of the three categories is different.

A two sample hypothesis test for unequal means was conducted, assuming unequal variances. The 'Student' *t*-test value is 8.489, with 9997 degrees of freedom. At a confidence level of $\alpha = 0.01$ the result is significant and the null hypothesis is rejected. This is to be expected, since there is no reasonable reason that the number of fatalities in the experimental group could be any more than the baseline. Certainly the two cannot be

equal as the implementation of the treatment in the experimental group favourably impacts on the measure.

5.3 Fidelity of Results

Agent-based simulation is not the only way in which a sequence of inflicted wounds could be generated and analysed, other discrete event models could be proposed. At the simplest, if uniformity of wounding in time was assumed (time invariance) then direct calculation might even be possible. However, these types of models discard the complexity of the battlefield in that wounds are not equally likely to be inflicted over the course of the battle but arise in response to triggered events. Therefore, it is difficult to calibrate a time-invariant model to the outcome of most historical battles.

The agent approach also lends itself to scoping future studies. For example, if each soldier was fitted with biomedical tracking, then they might also be fitted with a geo-locating device. Such a device would have affected the outcome of this battle because the artillery could be more responsively and accurately brought 'danger close' to their position without fear of fratricide. Casualties would also be less likely to be left of the battlefield, which occurred at Long Tan, and might be treated more quickly. It is difficult to directly calculate the impact of accurate artillery placement in reducing Australian casualties because it is not a part of the wounding and bleeding process. However, this could be a future extension to our model. This idea is important because the purpose of the study is to demonstrate a technique to contextualise a range of future technologies and not just to derive results for intravenous coagulants.

6. Conclusions

6.1 Effectiveness of Haemostatic Nanoparticles in Military Operations

This report employs an agent-based methodology to develop a historical model of the Battle of Long Tan, Vietnam 1966. The model is used to situate particular emerging and disruptive biotechnologies within the context of a designated military operation. In particular, the field of emerging medical practice has recently received attention in the study of Haemostatic Nanoparticles for the treatment of combat wounds. This research is of particular interest because the drug is intravenous, meaning that it is effective in controlling internal bleeding including blunt trauma. While there are a range of treatments for compressible external wounds; including pressure dressings, tourniquets and topical materials; there are no analogous treatments (approved for human use) for internal bleeding.

Through simulation, the efficacy of Haemostatic Nanoparticles is evaluated. The historical case study acts as the benchmark against which the insertion of the emerging technology is assessed. Our model determined that approximately 3.5% of combat fatalities in the Battle of Long Tan could have been avoided if this advanced clotting agent was available to Australian forces at that time. This result is broadly indicative of any modern engagement, where body armour is not employed, and where the principle mechanism of wounding is ballistic.¹⁵

A proportional reduction of 3.5% seems small, at first glance. However, only 50% of all battlefield fatalities are a result of exsanguination. The technology reduces mortality by 7% in wounds which are responsive to the treatment. It is also important to understand that standard casualty evacuation, even today, takes approximately 6 hours. In this sense, there are only a small number of affected casualties which would benefit from drug injections in the field. Triage Category I (priority 1, imminent) casualties will still die before standard evacuation if not otherwise treated. Triage Category III (priority 3, minimal) casualties will still survive even without treatment for 6 hours. Hence, casualties with a predicted lifespan of 3-4 hours are the principle beneficiary of the treatment as it will extend their lifespan sufficiently that they will survive until evacuation.

6.2 Future Research

Section 2.4 described the three phases to the implementation of our approach, being:

1. Benchmarking and verification using historical case studies in a single ABD.
2. Independent development of a second model in a different ABD for independent external authentication.

¹⁵ To extend our results to combat where body armour is used or the principle mechanism of wounding is explosive, the predicted rates of mortality in Table 12 would need to be updated.

3. Application of both models to selected case studies of interest to predict the impact of biotechnologies in current and future combat.

This report completes the first phase of the approach. It contains the results of contextualising an emerging biotechnology within the Battle of Long Tan. However, best practice dictates that a second agent-based model is independently developed to cross-test the results. This model may also be an agent-distillation but should not use the same software suite. This ensures that implementations are consistent and that outcomes are reproducible. As a future research program, a second model could be developed for this purpose.

Alternatively, models like those developed in this report can be used to identify areas for deeper investigation. The strength of an agent-distillation lies in its ability to quickly explore parameters of interest. However, its weakness lies in its inherent inaccuracy of measurement, which is systemic to the fidelity of the implementation. In this study, we have shown a proportionate 3.5% reduction in battlefield casualties. This result could be explored within a higher fidelity modelling environment. Additionally, the impact of combat medics and the availability of other forms of bandaging could be considered within such an environment.

Finally, future extensions of this work could be conducted to contextualise emerging biotechnologies within a range of different scenarios, including future operations. One particular technology of note is personal infantry monitoring, communications and GPS. In the Battle of Long Tan, artillery fire was extremely important. In the future, personal monitoring equipment would allow Joint Fires systems to target enemy positions without fear of fratricide. Additionally, within the Battle of Long Tan, friendly forces were abandoned on the battlefield. Soldier personal GPS devices would ensure that casualties are recovered, whenever it is practicable to do so. An extended model could be used to estimate the operational advantage, in terms of mortality figures, for soldier personal GPS devices in a similar manner to how this study has assessed advanced intravenous coagulants.

6.3 Summary

Ultimately, the implementation of this model has fulfilled its purpose; that being, a virtual simulation of the Battle of Long Tan for the contextualisation of future technologies. The model realistically and accurately recreates the historical account for that engagement and hypothesis testing confirms a statistically significant difference between the two simulation sets. However, the agent-based distillation is itself still no more than a first-order model, even if future extensions to the model were included. No greater accuracy in the measurements can reasonably be obtained without fundamentally increasing the fidelity of the model itself. To obtain results that are more accurate, a high-end agent model would need to be used. Hence, the agent-based distillation we use is of higher fidelity and more flexible than direct calculation, and encompasses the ability to simulate historical combat. In contrast it is also less accurate than higher fidelity models, but required substantially less time and invested effort to develop.

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Appendix A: Historical Account of Long Tan

Strategic Narrative

Strategic Context

Australia deployed Army, Navy and Air Force elements to the Vietnam War as a committed partner of the US. At the time it was feared that communism was spreading to fill the void left by the withdrawal of colonial powers in the aftermath of WWII. Resistance to this spread was central to the US strategy of Containment to which Australia also subscribed. This understanding had seen Australia to commit troops to the Korean War (1950-53), the Malayan Emergency (1950-60) and Confrontation with Indonesia (1963-66).

In 1954 a conference was convened in Geneva seeking to unify Vietnam which, with the collapse of French colonial power had separated into a communist north and an anti-communist south. The Conference agreed that general elections would be held in 1956 that would establish a single government for all of Vietnam. South Vietnam and the USA both demurred from this commitment on the grounds that the people of North Vietnam were not free to participate in genuinely free elections and the conference amounted to a partitioning of Vietnam. Subsequent to the agreement some 1,000,000 people moved from the north to the south while around 53,000 moved in the opposite direction. North Vietnam was unwilling to accept this partition and in 1960 established the National Front for the Liberation of South Vietnam to re-establish a unified Vietnam under communist rule.

The Viet Cong ('Vietnamese Communists') as this group was known proved to be too powerful to be contained by the government of the south and, as a result, steadily escalating US support was needed if South Vietnam was to survive. The rapid ramping-up of US effort from about 1965 was seen as entirely consonant with Australia's interests and as a result was matched by steady increases in Australia's contribution.

National Intent

As part of this, in early 1966 Australia decided to commit a brigade of two infantry battalions to the war. The force was formed around HQ 1 Brigade and was designated 1ATF. Rather than being attached to a US division, 1 ATF would take responsibility for its own Tactical Area of Operations, the province of Phuoc Tuy, and would be an independent command under the operational control of US 2 Field Force (II FFV), a corps-level headquarters based in Bien Hoa. This would both increase the profile of the Australian commitment and allow the force to use its own doctrine and techniques for counter-insurgency that had matured over the preceding two decades of operational experience.



Figure 5: Phuoc Tuy Province¹⁶

Military Objectives

1 ATF was tasked with dominating its area of responsibility and conducting operations throughout Phuoc Tuy as required. Its principal objective was to secure Route 15 for military movement to ensure allied control of the port at Vung Tau. At the same time it sought to extend government authority across the province. Australian doctrine emphasised establishing a base and spreading influence outwards to separate the insurgents from the population. Having established at Nui Dat on 5 Jun 1966 they aimed to form a permanent presence between the Viet Cong and the inhabitants. 1 ATF would focus on destroying Viet Cong forces in the province, while security of the towns and villages remained a South Vietnamese responsibility.

¹⁶ Online resource: www.hq1atf.org/maps.htm accessed June 2014.

Operating Environment

Terrain

The Long Tan rubber plantation consisted of young rubber trees that were about five years old with trunk diameters of between 100 and 150 mm. They provided no effective cover from fire. The trees were regularly spaced in rows about 5 metres apart with about 5 metres between trees. The photograph below shows the plantation at about the time of the battle. Visibility in the rubber was about 150 metres although this dropped to 100 metres during rain and even less in particularly heavy downpours. Firsthand accounts record that the ground was bare of vegetation and that heavy rain caused the earth to splash into a 'red mist' up to 500 mm high at times. This meant that anyone in a prone fire position was difficult to detect while an assaulting infantryman standing up could be seen.



Figure 6: Long Tan Rubber Plantation¹⁷

The edge of the heavy scrub that covered Nui Dat 2 and its surrounds provided a visual barrier to an observer in the rubber.

Weather

The Phuoc Tuy wet season extends from May to November. August night-time temperatures average in the mid-twenties while daytime temperatures average in the low-thirties. On 18 Aug the weather followed the usual pattern of gradually increasing temperature and humidity through the day culminating in heavy rain beginning at around 1645. This rain continued throughout the battle.

Sunset on 18 Aug was at 1810 with nautical twilight beginning at 1656 and ending at 1858. Because of the very heavy rain, at ground level, it was becoming difficult to see clearly by around 1800.

¹⁷ Attributed to Tacintop from the Wikimedia Commons online repository. Licenced to Public Domain for any purpose. Filename: The_site_of_the_Battle_of_Long_Tan_in_2005.

Friendly Forces

Concept of Operations

At 02:43 on 17 August Nui Dat received between 60 and 100 rounds of 82 mm mortar, rocket and 70mm artillery – the latter probably fired from a WWII Mk92 Japanese infantry gun located about 2,000m to the east of the base. In this bombardment, the task force sustained some 24 wounded. In response a number of company-sized fighting patrols were mounted to locate the firing points and the direction of the Viet Cong withdrawal. One of these patrols was mounted by D Company 6 RAR which was assigned the mission to search for and destroy the enemy force that mortared and shelled the 1ATF base on 17 Aug. Its assigned AO for this mission was the Long Tan rubber plantation.

The Australians held a paradigm of counter-insurgency in which they were the hunters and the insurgents were their prey. The search and destroy mission required first finding the enemy and then prosecuting the resulting contact by engaging them in close combat in a combined arms setting. The hallmarks of Australian infantry minor tactics at the time were encompassed in the catch-cry ‘speed and aggression’.

Command and Control

Communications within the infantry company rested on a combination of combat net radio using AN-PRC 77/ 25 VHF radios and oral orders. The company radio connectivity is shown in the diagram below.

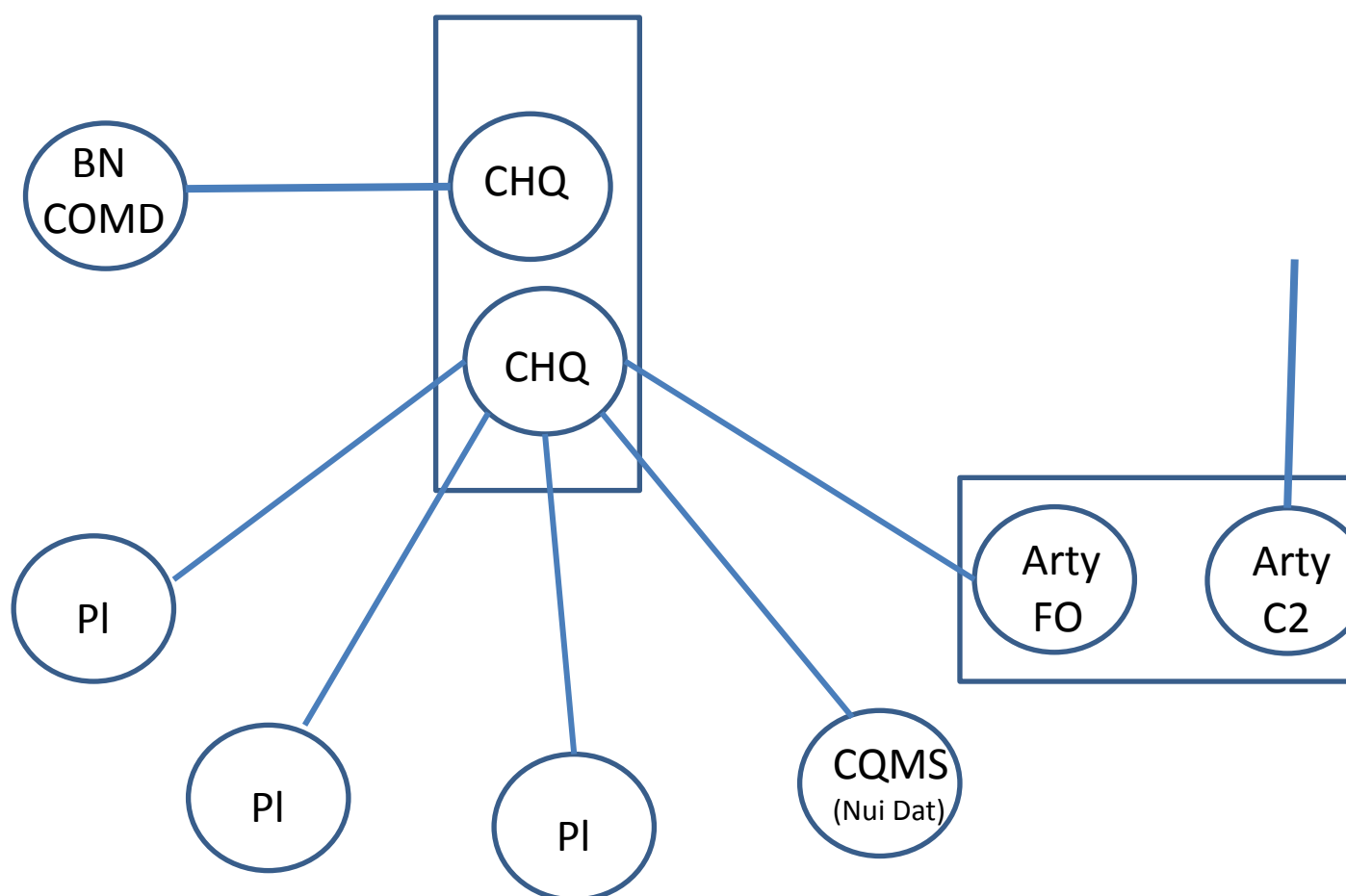


Figure 7: Company Radio Net Diagram

Below platoon level simple messages could be passed by field signals with more complex communication relying on word of mouth. Once fighting started these shouted communications were impaired by the noise and by gaps in the chain of communication as a result of casualties.

Rules of Engagement

An area around the 1 ATF base at Nui Dat, which roughly corresponded with the effective range of close support artillery based there, was a declared Free Fire Zone (FFZ). Villages within this area were relocated and the civilian population was prohibited from re-entering. Any unauthorised movement by foot or vehicle within the FFZ would be assumed as hostile and could be fired on without warning. D Company's patrol on 18 Aug took place entirely within the 1 ATF FFZ.

Australian soldiers remained subject to the laws of armed conflict and the Geneva Conventions.

1 ATF ORBAT

The structure of 1 ATF at the time of the battle of Long Tan is as follows. Only elements involved in the battle on the first day (Operation Vendetta) are included (elements in Operation Smithfield on 19-22 August 1966 are not).

Table 18: 1 Australian Task Force

Unit	Remarks
Main Effort	
HQ 1 ATF	Situated at Nui Dat
1 Field Regiment RAA 103rd Field Battery 105 th Field Battery 161 st Battery (NZ) A Battery 2/35 Artillery Battalion (US)	6x 105mm L5 pack Howitzer 6x 105mm L5 pack Howitzer 6x 105mm L5 pack Howitzer 6x 155mm M109 SP Howitzer
6 RAR	D Coy (105 men)
Relief Force	
6 RAR	A Coy (100 men) and HQ B Coy
3 Troop 1 APC Squadron	10x M113 APC ¹⁸
Air Support and Resupply	
9 Sqn RAAF	2x UH-1B Iroquois (6x used in CASEVAC)
Close Air Support Elements	3x US F4 Phantoms

D Company 6 RAR

The D Company 6 RAR (D/6) group consisted of 105 Australian infantrymen and a Forward Observer (FO) party of 3 NZ artillerymen. The infantry company comprised a company HQ and three platoons, numbered 10, 11 and 12, each with a standard organisation of one officer and 33 OR. Each Platoon was organised into a platoon HQ (Lieutenant, Sergeant, radio operator and a batman); and three rifle sections. The rifle sections had a standard organisation shown in the table below.

Table 19: Standard Section Organisation

Group	Personnel	Armament
Commander	1 x CPL	1x 5.56mm M16
Scout	2 x PTE	1x 5.56 M16 1x 7.62 L1A1 SLR
Gun	1x LCPL (SECT 2IC) 2x PTE	1x 7.62mm M60 GPMG 2x 7.62 L1A1 SLR
Rifle	4x PTE	4x 7.62 L1A1 SLR

¹⁸ Two of these were sourced for the operation from 2 Troop.

As well as their standard weapons some soldiers carried M26 fragmentation grenades or Mk 83 coloured smoke grenades.



Figure 4: 6 RAR National Servicemen 1966¹⁹

Due to absences for various reasons, on the day of the battle D company platoons were each reduced to less than 30 personnel. 11 Platoon's strength was 28 comprising a HQ of four and three sections (numbered 4, 5 and 6) each of eight men. It is not certain but this would probably have been managed by reducing each of the scout and rifle groups by one man.

Casualties

Casualties either administered self-first aid or were aided by their comrades. Each soldier carried a First Aid Dressing and a Shell Dressing on their person and a slightly more expansive first aid kit was carried at section level. Stretcher tops were carried by each section and stretcher poles were intended to be won locally.

If evacuation was required, and when practicable, casualties were assisted to a casualty aid point established at company HQ. This was manned by the company medic. From there, if the situation allowed, and depending on the priority of the casualty, evacuation could be by ground vehicle or helicopter

During the Battle of Long Tan, mass casualty coordination was not possible until approximately 20:50, after reinforcement of D Company by elements of the relief force. At that time, 5 personnel were confirmed Killed-in-Action (1 from 3 Troop), 16 wounded, and

¹⁹ Australian War Memorial. Not attributed. Collection item P06136.001 by unknown photographer.

16 unaccounted. Fatalities were loaded into the APC which left at 22:45, while medical evacuation proceeded by air. Casualties were treated at the Australian hospital at Vung Tau and the evacuation was completed just after midnight.

Operation Smithfield on the 19th August reclaimed thirteen additional dead and two additional wounded. This accounted for all missing Australian personnel (the original report of 16 unaccounted being overstated by one).

Enemy Forces

Enemy Strategic Intent

At this stage of the war – and up until the ‘Tet Offensive’ in 1968 – the North Vietnamese had decided to match and contest the US build-up in what became known as the ‘big unit’ phase of the war. This saw substantial infiltration of North Vietnamese Army (NVA) units into the south and a general willingness to seek battle.²⁰ Long Tan fits neatly into this general approach. The Viet Cong sought to bring the newly arrived Australian forces to battle to inflict a major defeat and heavy casualties and thereby to undermine Australian political will to continue its support of South Vietnam and the US.

Enemy Tactical Intent and Concept of Operations

It is not clear whether this intent was to be pursued by mounting a deliberate attack on the 1ATF base at Nui Dat (the Australian understanding) or by drawing a sizeable force out of the base and into an ambush (the Viet Cong claim). In the event the Viet Cong plan is relatively unimportant because, whatever it was, it misfired and what eventuated was an encounter battle between two moving forces. Throughout the battle the VC sought to establish the precise locations and strengths of the Australian force. This effort was hampered by the dispersion and manoeuvring of the Australians and the weight of continuous artillery fire.

What is important is that the VC force was large, well organised, well-armed, well-trained and seeking to engage the Australian forces in a decisive battle. This was in stark contrast to Australia’s previous experience of counter-insurgency warfare.

Enemy Organisation and Equipment

Planning and control of the operation was the responsibility of HQ 5 Division, whose responsibilities included Phuoc Tuy. HQ 5 Division commanded two regiments numbered 274 and 275. Only the latter was directly involved in the battle. Provincial Mobile Battalion D445 (Regional Force) was also under command.²¹

275 Main Force Regiment was made up of full-time fighters. They wore the pith helmet and green uniforms common to the NVA, carried the same weapons, and could operate in battalion or regimental strengths. The Regiment consisted of a headquarters and three battalions. Each battalion consisted of a HQ, three rifle companies and a heavy weapons company as shown in the diagram.

²⁰ The North Vietnamese military objective for 1966 included the goal for all of South Vietnam was to strive to annihilate between 30,000 and 40,000 US troops and 200,000 puppet [South Vietnamese] and satellite [allied] troops and to destroy 1,000 enemy aircraft of all types. Warren Wilkins, *Grab Their Belts to Fight them: the Viet Cong’s Big Unit War against the US*, Naval Institute Press, Annapolis Md 2011 p.135.

²¹ HQ 5 Div was also reinforced by COSVN assets including elements from Z39 artillery battalion which used the 70mm Mk 92 Gun on 17 Aug.

In the lead-up to the battle the Regiment seems to have been brought up to strength by incorporating the NVA D605 Battalion as its third battalion and was probably close to its establishment strength of around 1500 men.²² In addition to its infantry battalions the Regimental HQ had a mortar company (82mm mortars), a HMG company (12.7mm Dshk) and an anti-tank company (70mm RCL) as well as communications, transport, medical and engineer companies.

D445 Battalion was a regional force battalion comprised of four companies of full-time soldiers. Regional Force units normally served within or close to their home provinces. They were not as well armed as main force units and usually operated as small units that seldom exceeded company strength.²³ At the time of the battle D445 probably numbered between 380 and 400 men.²⁴ It seems probably only the 1st and 2nd companies and elements of the weapons companies were engaged at Long Tan.

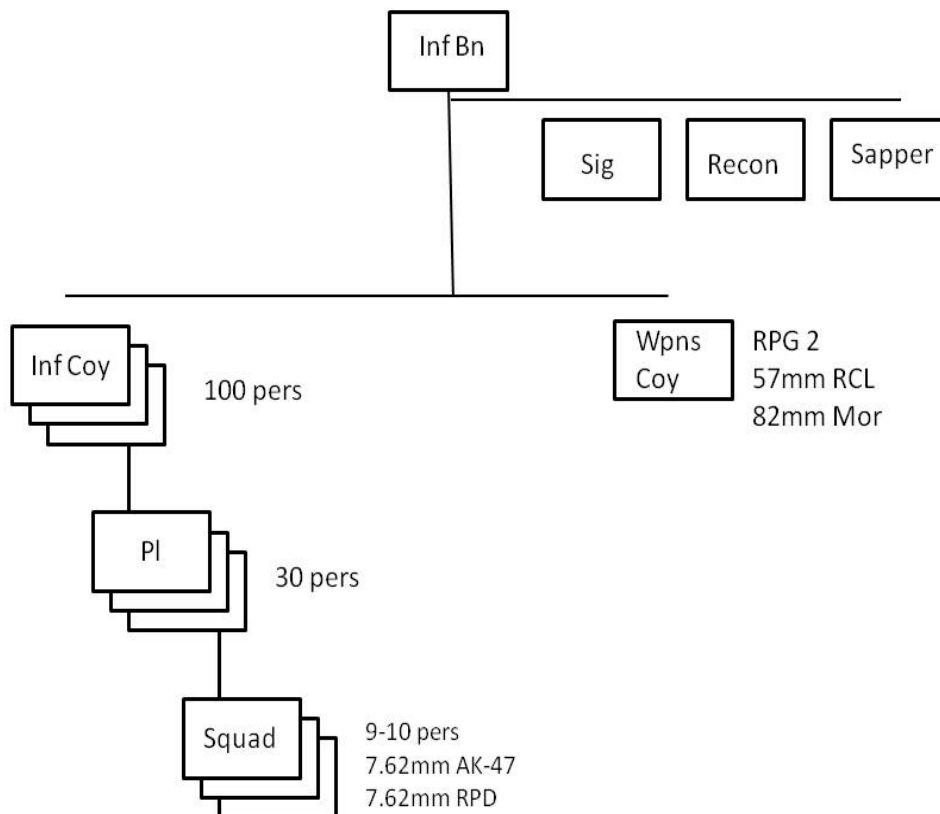


Figure 5: 275 Main Force Regiment

²² Email from BRIG (ret) Ernie Chamberlain (formally AustInt) 5-Feb 2014.

²³ http://en.wikipedia.org/wiki/Viet_Cong_and_PAVN_strategy_organization_and_structure accessed 5 Feb 14.

²⁴ E. Chamberlain D445 Their Story Part Two Annex D p4.

A militia company comprising about 80 personnel (mainly women) was also present and dedicated to battlefield clearance and casualty evacuation.

VC communications were austere. Radios were used only between divisional and regimental headquarters. Below that, field telephones were established between regiment and battalion and probably between battalion HQ and elements of the heavy weapons company. Apart from that, runners and bugles were the primary means of battlefield communication. This meant that there was little shared situational awareness on the VC side until after 1800 hrs when D company consolidated and by which time the mounting 1 ATF responses and VC casualties meant that it was probably too late.

Lines of Operation

Lead up to the Battle

From late-July US EW had tracked the radio of 275 Main Force Regiment moving from the regiment's base area in the vicinity of Xuyen Moc some 20 km to the east of Nui Dat. By 14 Aug it had settled in the vicinity of the Nui Dat 2 five kilometres due east of the 1ATF base. However, despite quite intensive patrolling in the first half of August, including company sweeps in the vicinity of Nui Dat 2 on 15 and 16 Aug, the TF had been unable to detect any unusual activity.²⁵

At 02:43 on 17 August Nui Dat received between 60 and 100 rounds of 82 mm mortar, rocket and 70mm artillery – the latter probably fired from a WWII Mk92 Japanese infantry gun located about 2,000m to the east of the base. In this bombardment, the TF sustained some 24 wounded. In response a number of company-sized fighting patrols were mounted to locate the firing points and the direction of the Viet Cong withdrawal.

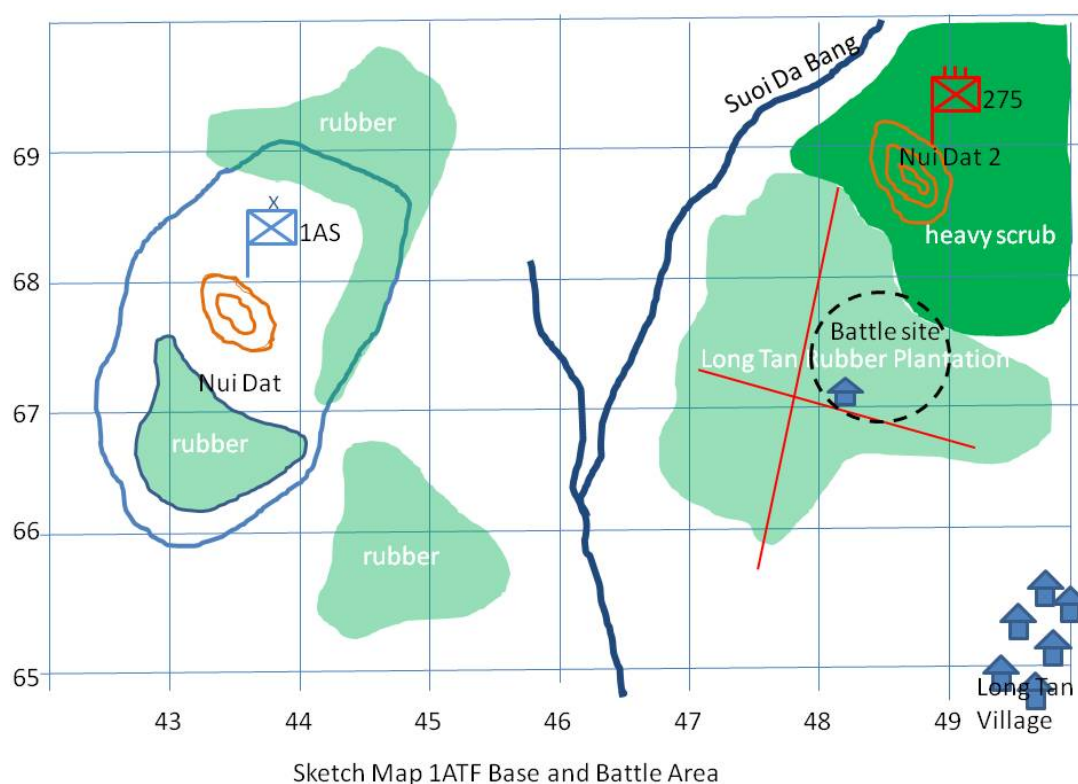


Figure 6: Sketch Map 1 ATF Base and Battle Area

²⁵ The fact that this radio was so clearly and accurately tracked but that intensive patrolling failed to disclose a regimental headquarters adds weight to the proposition that this radio was a bait intended to attract an Australian response. (email from BRIG (ret) Ernie Chamberlain (formerly AustInt) 5 Feb 2014.

One of these patrols was mounted by D Company 6 RAR which was assigned the mission to search for and destroy the enemy force that mortared and shelled the 1ATF base on 17 Aug. Its assigned AO for this mission was the Long Tan rubber plantation. The location of the battle is shown in the sketch map.

Chronology of the Battle

The operations of 11 Pl of D Coy are the focus of this scenario but to make sense of them it is necessary to understand the company context. The Company patrol began at 1500 hrs and the battle began when 11 Pl contacted a small enemy group at 1542 hrs. 11 Pl followed-up that initial contact with speed and aggression. This extended the company formation and led 11 Pl into an encounter battle with a force that was originally identified as a platoon and successively as a company and battalion. During this encounter battle 11 Pl became pinned down by superior forces and its own mounting casualties. The attempts by the remainder of the company to manoeuvre to relieve 11 Pl effectively disguised the company's precise locations and strengths and prevented the enemy from achieving a decisive concentration of force. By the time the VC had developed sufficient situational awareness, at around 1800 hrs, 1 ATF responses (reinforcement, replenishment and overwhelming artillery fire) were in train and effectively took victory beyond the reach of the VC. The detailed chronology and conduct of the battle is described in Annex A.

11 Platoon Behaviour in Scenario

At the start of the battle the Australian troops were well rested and in good physical condition. Their weapons and personal equipment were serviceable and they were carrying standard ammunition loads.

The keywords for Australian minor tactics in Vietnam were 'speed and aggression'. Australian contact drills embodied classic encounter battle approaches of seeking to build up combat power as quickly as possible in order to seize and retain the initiative. This meant that, when first contacted 11 platoon would have moved towards the threat as quickly as possible – seeking to dominate it. This speed and aggression by 11 led D company to be dispersed beyond what was normal practice. This would prove to be an important factor later when the company's dispersion prevented the VC from establishing, until it was too late, solid situational awareness of the size, extent or precise locations of the force they were facing

Once it was established that the enemy was a superior force the platoon would have consolidated to establish a measure of all-round defence while further assessing the situation. Once consolidated 11 Platoon was effectively immobilised by its own mounting casualties and by enemy pressure and the platoon went into survival mode, attempting to keep the enemy at arm's length through small arms fire and artillery. At this stage options for manoeuvre were available only at company level and higher.

When darkness, shortage of ammunition and casualties made continued survival unlikely the platoon broke out. This was not a structured bounding movement rearward – but has been characterised as a ‘dash’. The execution of this movement was hampered by the conditions and by the difficulties of communicating by voice messages passed along a line of prone infantrymen in the midst of a battle.

Enemy Behaviour in Scenario

For the VC this was a deliberate action that had been in preparation for a number of months. 3 Battalion of 275 Regiment had completed a 112 day infiltration from North Vietnam a few weeks earlier but can be considered to be well rested, well equipped and well trained. At the start of the battle the VC weapons, equipment and personnel were in good condition and were prepared for battle.

The VC, although conducting a deliberate action, were wrong-footed by the speed and dispersion of D Company. From the VC perspective, wherever they probed in the rubber they seemed to encounter Australian troops and they were unable to establish precise locations, strengths and extremities of positions until after the withdrawal of 11 Platoon at 1800 hours.

The VC were hampered by poor tactical communications. For example, the probing forces sent to establish the extremities of the 11 platoon position were forced to move in wide arcs because of effective small arms fire by 11 Platoon, this caused them to bump into 10 and 12 Platoons on occasion and to come under effective artillery fire. Having gathered some information, this then had to be carried to the next command echelon by a messenger who had to negotiate the journey through the rubber and the battle. If he made it through, and found the intended commander, he would then have to carry new orders back to his own force. This consumed time and meant that the VC were always a half-step out of tempo. The uncertainty that resulted meant that the VC were largely prevented from coordinated manoeuvre and, until about 1800 hours, were left simply to continue to press on what they had found and fixed – in this case 11 Platoon. This made them prey to the full weight of artillery fire fired from Nui Dat.


Conclusion


In retrospect the Battle of Long Tan holds offers many insights. Within the Australian Army generally, the experience of counter-insurgency over a long period had established a conviction that 'we were the hunter' and that finding the enemy was the biggest challenge. Despite US experiences since mid-1965, and the experiences of 1 ATF since their arrival, the reality of facing an aggressive, well-trained and well-armed enemy had not yet been fully internalised and as a result D/6 and 11 Pl were placed in unexpected circumstances. Somewhat paradoxically however, this battle had such an impact on the enemy in Phuoc Tuy that henceforth they conformed more to the Australians' initial expectations of insurgents.


Despite the unexpected circumstances in which they found themselves the soldiers of D/6 demonstrated the absolute importance of good training and cool leadership. As both sides attempted to make sense of the noise and confusion in the rubber, energetic leadership at the company level and good battle discipline from platoons and sections denied the enemy the initiative that was rightly theirs. At the same time the high level of combined arms cooperation proved decisive. To some extent it could be said that, against the odds and with considerable heroism, the infantry survived and by so doing created the opportunity for the artillery to win. Similarly, the actions by the cavalry and by 9 Sqn RAAF in effecting ammunition re-supply through the canopy during a monsoonal downpour were also decisive in their own way. It was this combined arms excellence that truly separated the two sides and which was even further improved as the war progressed.


Appendix B: Weapons Systems in Long Tan

Australian Weapons Systems

L1A1 Self Loading Rifle	
	Origin: Belgium
	Cartridge: 7.62x51mm
	MV: 823 ms ⁻¹
	Rate of Fire: 650 - 700 rpm
	Range: 800 m (max)
	Weight: 4.34 kg (unloaded)
	Magazine: 20 rnd
Description: Standard Australian version of the Belgian designed FN-FAL. Reliable and accurate with a heavy high-velocity round able to penetrate foliage with high lethality.	


M-16 Assault Rifle	
	Origin: United States
	Cartridge: 5.56x45mm
	MV: 948 ms ⁻¹
	Rate of Fire: 700 - 950 rpm
	Range: 550 m (max)
	Weight: 3.26 kg (unloaded)
	Magazine: 20 rnd
Description: The 5.56mm projectile was reputed to have limited lethality and to be adversely effected by even light foliage. The M16 was also unreliability if not routinely cleaned. Nonetheless, its light weight, relatively short length and fully automatic mode made it a weapon favoured by scouts, section commanders and signallers. The M16 was relatively new in Australian service at this time, progressively replacing the Owen SMG.	


M60 General Purpose Machine Gun	
	Origin: United States
	Cartridge: 7.62x51mm
	MV: 853 ms ⁻¹
	Rate of Fire: 500 - 650 rpm
	Range: 1,100 m (max)
	Weight: 10.5 kg (unloaded)
	Magazine: 100 rnd (belt)
Description: The M60 was relatively new in Australian service at this time and was replacing the Bren Gun which had been in use since WWII. The exposed belt of the M60 was prone to feed dirt into the mechanism and to stretching as a result of being carried outside a bandolier. This made the weapon unreliable at the time of the battle.	


L5 Pack Howitzer (OTO Melara Mod 56)	
	Origin: Italy Caliber: 105 mm Ordnance: L10 Fuse: Point Detonating MV: 416 ms ⁻¹ Rate of Fire: 6 rpm (max) 2 rpm (sustained) Range: 2,500 m (min) 10,575 m (max) Safe Range: 150 m Weight: 483 kg (unloaded)
	Description: The low weight of the L5 meant that the gun could air-lifted by sling or towed by vehicle type Land-rover upwards. In the Vietnam war a limited array of fuse and ammunition combinations were available, primarily point detonating high explosive. However, firing through canopy vegetation in Vietnam required fuse-delay to avoid a premature burst but not so much that the projectile buried itself in earth before detonating.


M109 Self-Propelled Howitzer	
	Origin: United States Caliber: 155 mm Ordnance: M126 Fuse: Point Detonating MV: 564 ms ⁻¹ Rate of Fire: 6 rpm (max) 3 rpm (sustained) Range: 4,000 m (min) 14,600 m (max) Safe Range: 200 m Weight: 23,586 kg Speed: 56 km/h Range: 349 km
	Description: The heavier 155mm projectile produced larger fragments and had a larger safety distance. It was primarily directed to engage targets in depth – beyond the immediate close contact area.

Viet Cong Weapons Systems

RPD Light Machine Gun	
	Origin: Soviet Union
	Cartridge: 7.62x39mm
	MV: 735 ms ⁻¹
	Rate of Fire: 650 - 750 rpm
	Range: 1000 m (max)
	Weight: 7.4 kg (unloaded)
	Magazine: 100 rnd (drum)
Description: A Soviet design originating in 1943, the RPD remains in-service in many countries today. The drum magazine contained a 100 round belt and protected it against the environment (dirt / moisture) and accidental stretching of the belt; both being a source of unreliability in the US equivalent M60.	

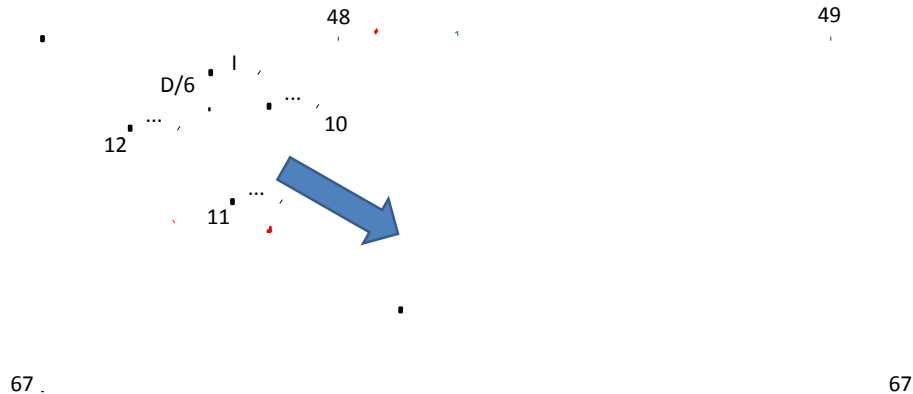
AK-47 Assault Rifle	
	Origin: Soviet Union
	Cartridge: 7.62x39mm
	MV: 715 ms ⁻¹
	Rate of Fire: 1000 rpm (cyclic)
	Range: 400 m (max)
	Weight: 3.47 kg (unloaded)
	Magazine: 30 rnd
Description: The AK-47 is a Soviet designed assault rifle manufactured in many countries around the world. It is simple to operate and highly reliable. However, when fired in fully automatic mode it had a tendency to pull upwards and to the right which markedly reduced its effectiveness.	

RPG-2 Recoilless Rifle	
	Origin: Soviet Union
	Warhead: 82 mm
	Type: PG-2 HEAT
	MV: 84 ms ⁻¹
	Rate of Fire: 3 rpm
	Range: 5 m (min) 150 m (max)
	Weight: 2.83 kg (unloaded)
Description: The RPG-2 was of low effectiveness against armoured vehicles and was often employed to burst against tree trunks. This offered a means of semi-indirect engagements of prone troops. The small HEAT warhead was relatively inefficient as a blast or fragmentation source and the innate inaccuracy made it difficult to apply in a jungle setting or against the rubber trees at Long Tan.	

DShK Heavy Machine Gun	
	Origin: Soviet Union Round: 12.7x108mm MV: 850 ms ⁻¹ Rate of Fire: 600 rpm Range: 2,000 m (max) Weight: 157 kg (wheeled) Magazine: 100 rnd (belt)
Description: The Soviet designed DShK is able to be fitted to a vehicle, tripod or the wheeled carriage (pictured) which was the preferred mount for the VC. The rubber trees at Long Tan would have been essentially transparent to the heavy 12.7mm projectile.	

Appendix C: Chronology of Long Tan

Stage 1: Initial Skirmish and Follow-up

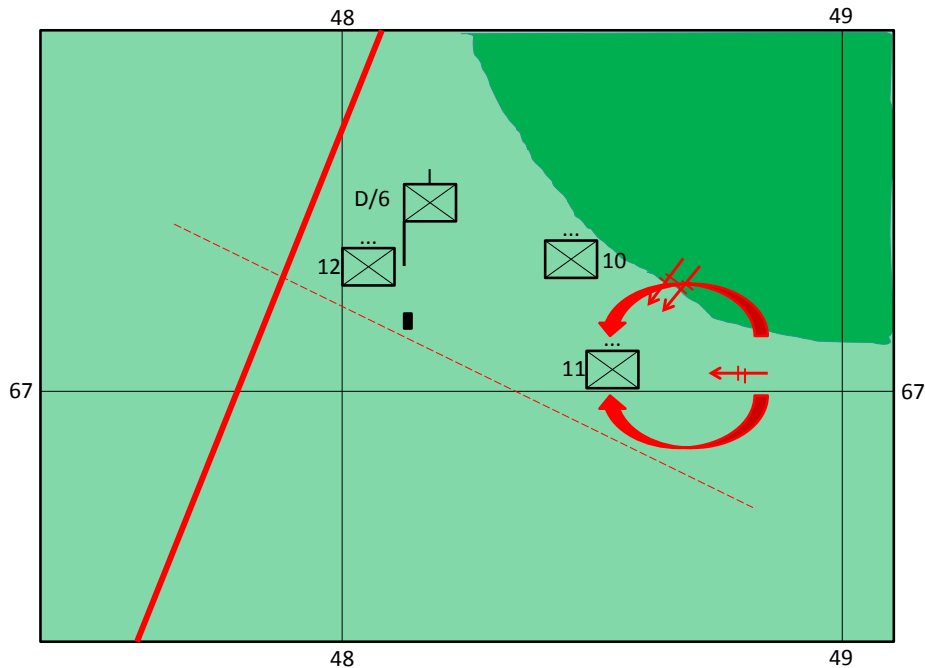


48 49
Stage 1 – 1500-1600 hrs Initial Skirmish and Follow-up

D/6 and 1 ATF Situation	
1500 hrs	D/6 left a company harbour at YS 473673 and patrolled East with two platoons. Company covered approximately 400x400m.

11 Platoon Situation	
1540 hrs	11 Pl conducted an obstacle crossing drill when it reached the road at YS478673. When the first two sections and the first half of platoon HQ had crossed, a group of 6-8 VC approached along the road from the south. This effectively placed them into the centre of 11 Pl. The PL SGT engaged the group with M16 wounding one. The enemy fled east. The VC were wearing green uniforms and pith helmets and carried AK 47s indicating they were NVA or Main Force but this inference was not drawn at the time.
1542 hrs	Artillery was called on the enemy withdrawal route. 11 Pl continued east now with three sections up in extended line; 6 sect on the left, 4 in the centre and 5 on the right. It is not clear but MG groups would probably have been at the right of each sect. With 5-10m spacing between men, platoon frontage was probably around 200 -250m. This formation would be used for searching and assaults and not when contact with a superior force was expected.

Stage 2: 1608 - 1630 Isolation of 11 Platoon

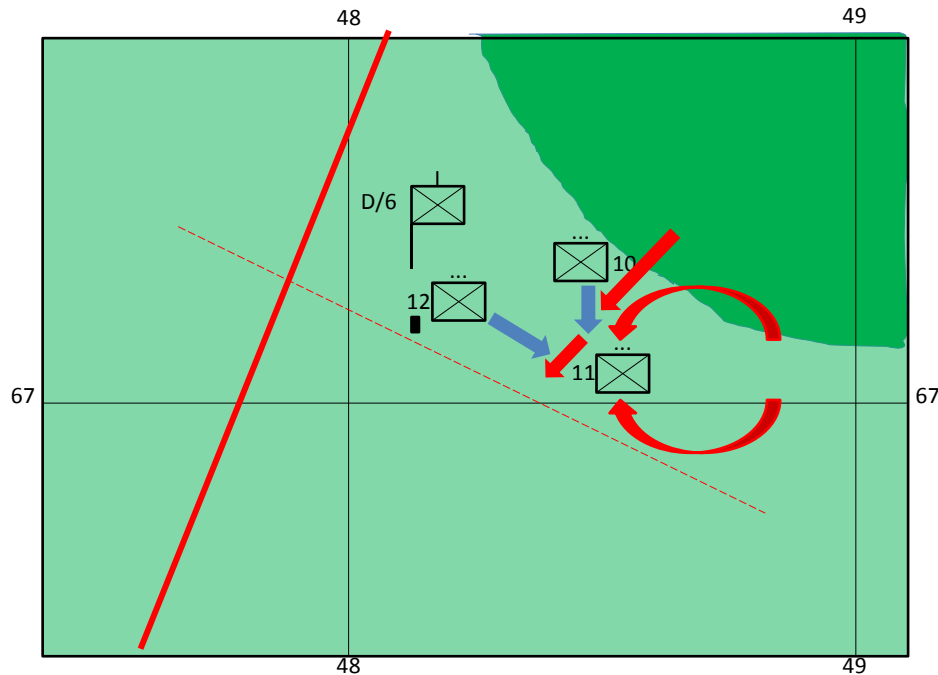


Stage 2 - 1608 - 1630 Isolation of 11 Platoon

11 Platoon Situation	
1608 hrs	11 Pl is engaged from their north-east by at least two 7.62mm RPDs and an indeterminate number of AK47s from YS487674. Platoon commander reports suspected contact with an enemy platoon and calls for artillery fire. Initial engagement kills four and wounds two men in the left hand section.
1609 hrs	11 Pl commander orders the right-hand section to sweep across the front of the platoon to provide fire into the contact area. As they move they are engaged from the east by a large group estimated at company size. The sweep is halted as they move to face south. Platoon starts to establish all-round defence with a strong emphasis on the east and south (an L-shaped layout facing south and east - each leg is probably less than 60m long). Pl commander reports being attacked from left, front and right by a company sized force. The enemy is kept at bay primarily by small arms and MG fire.
1625 hrs ~	Pl COMD 11 PL killed (GSW to throat). Artillery fires closer to 11Pl.

D/6 and 1 ATF Situation	
1616 hrs	Artillery battery fired in support of 11 Pl. Uncertainty to the location of the platoon and enemy means that this fire is initially in depth. DF safety distance for 105mm artillery was 250m from FLOT. COY COMD orders 11 Pl to withdraw. COY HQ and 12 Pl, which had been following in formation, received 20 rds of 60mm mortar fire and displaced 1-200m northeast to YS482674 to avoid impact area. This increased their separation from 11 Pl.
1630 hrs	Artillery support provided by a full reinforced regiment (3x105mm bty and 1x 155mm bty) enabling the engagement of multiple targets.

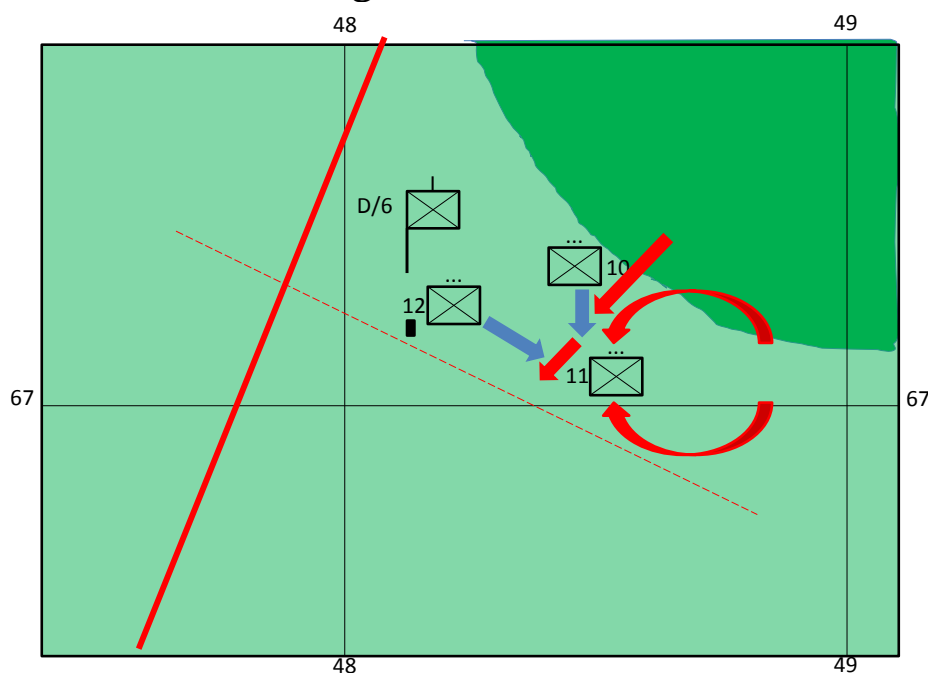
Stage 3: 1630 - 1800 Attempts to Relieve 11 Platoon



Stage 3 – 1630-1800 Attempts to Relieve 11 Platoon

11 Platoon Situation	
1630 hrs	The enemy continues frontal pressure on 11 Pl while probing to the flanks. The action by 10 Pl disrupts the move around the northern flank while the fire of the right hand section of 11 Pl hampers enemy movement to the south – pushing the enemy into a wider manoeuvre. 11 Pl assesses enemy strength as a battalion and reports repeated company sized assaults from its east. The enemy has closed to within 50m of 11 Pl's front.
1635 hrs ~	11 Pl radio is disabled for a period due to antenna being shot away.
1700 hrs - 1730 hrs	11 Pl continued to receive heavy fire from their north and company sized assaults from their east. They could see the enemy moving around to their south. The weight of supporting artillery fire was becoming critical to the survival of 11 Pl and had been walked in to about 100m from their perimeter. They were low on ammunition and had a large number of dead and wounded. At this stage about 50% of the platoons were casualties. The pressure on the survivors meant that any first aid had to be self-administered. The PL SGT assessed they could not withdraw because they had too many wounded to carry.
1750 hrs	PL SGT 11 Pl assesses they cannot hold-out much longer and decides to withdraw. There is a monetary lull in pressure from their east (largely due to the impact of artillery fire) and the 13 survivors (including six walking wounded) break contact and move to the west in what had been described as 'a dash'. They leave 15 MIA (believed dead). In the twilight they accidentally break into two groups both of which see a smoke grenade thrown by 12 Pl.

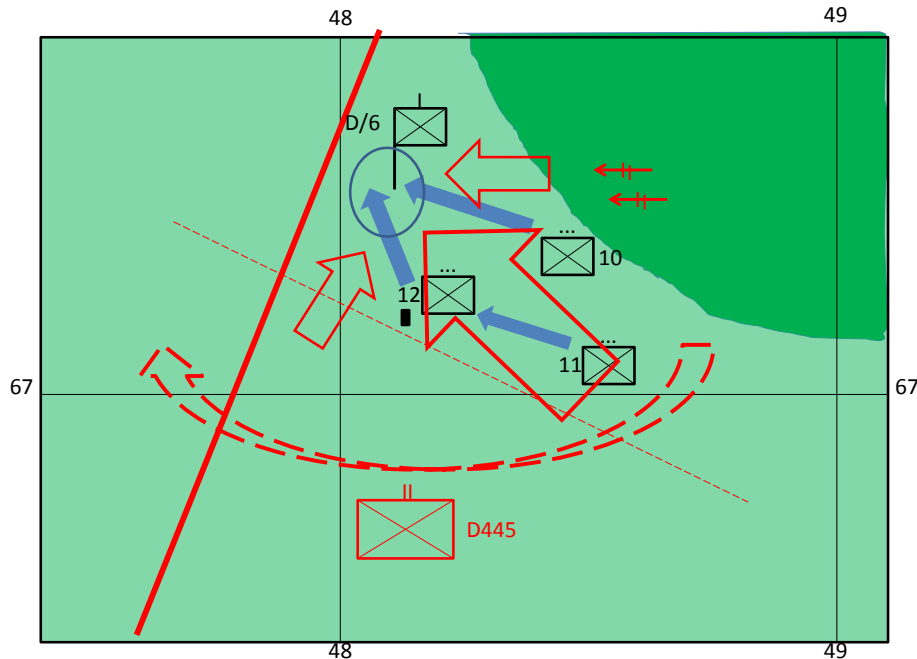
Stage 3: Continued



Stage 3 – 1630-1800 Attempts to Relieve 11 Platoon

D/6 and 1 ATF Situation	
1630 hrs	10 Pl were directed to attack from the north to relieve 11 Pl. Having moved about 300m they strike a large group of enemy manoeuvring between them and 11Pl. They engage this group but are then themselves engaged by a large group to their left flank. They suffer six WIA. 10 Pl radio is destroyed and, for a time both 10 and 11 Pls are out of radio contact.
1645 hrs	Heavy rain begins, visibility reduced to less than 100m and at times down to 50m. Splashes cause 'red mist' to rise to knee height.
1700 hrs - 1710 hrs	D Coy HQ and 12 Pl began to move to the south east to attempt to re-establish contact with 11 Pl. As they began to move radio contact was re-established with 10 Pl. Now aware that 10 Pl had casualties Coy HQ halts and establishes an aid post. One sect of 12 Pl is held at CHQ while the 10 Pl is sent to the south and east to re-establish contact with 11 Pl.
1730 hrs	10 Pl return to CHQ and establish a hasty defence facing east.
1740 hrs	Enemy began to probe the CHQ/ 10 Pl location.

Stage 4: 1800-1900 Consolidation of D Company

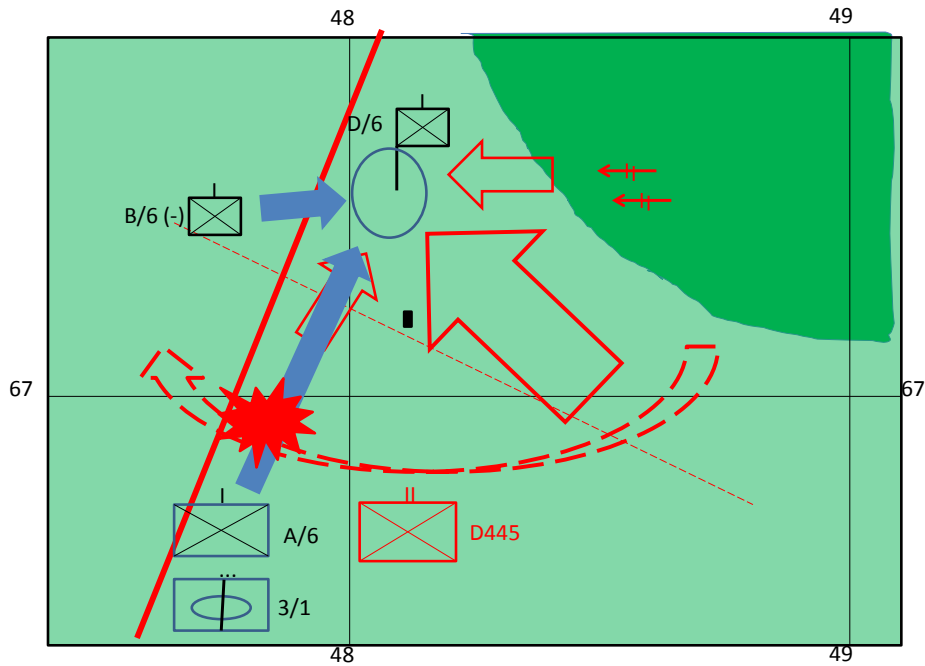


Stage 4 - 1800-1930 hrs Consolidation of, and Attacks on, D Company

11 Platoon Situation	
1800 hrs	<p>11 Pl join 12 Pl and begin to fight their way back to CHQ resisted by the enemy probing and follow-up forces the latter mainly operating in small uncoordinated groups. One enemy group of about 60 men moving to assault CHQ was ambushed and its attack disrupted.</p> <p>The seven able-bodied men of 11 platoon are allocated a position on the north-western part of the company perimeter and take no further part in the action.</p> <p>In the battle, Australian casualties totalled:</p> <ul style="list-style-type: none"> • 18 dead - all from gunshot wounds most were in the head or upper body • 18 wounded - two of whom remained on the battlefield overnight (one had a chest wound and the other had been shot in the mouth and then, during the withdrawal, in the leg).

D/6 and 1 ATF Situation	
1830 hrs	11 and 12 Pl re-join 10 Pl and CHQ and D/6 is consolidated in some dead ground that offered an effective reverse slope defence from the east and south.
1830 hrs - 1900 hrs	The company is subjected to near continuous company-sized human wave assaults from multiple directions but with the enemy main effort apparently being from the south-east. Friendly artillery fire is called to within 25m of the perimeter.

Stage 5: 1840-1900 Relief of D Company



Stage 5 - 1840-1900 Relief of D Company

D/6 and 1 ATF Situation	
1840 hrs - 1900 hrs	A/6 together with the CO and tac pty from Bn HQ mounted in 10 APCs from 3Tp/1 APC Sqn move along the axis of the road from the south. They contact and disrupt two companies from D445 battalion in two separate contacts. POW interrogations later indicated these units were intended to act as cut-offs in support of the 275 Regt assault. The en withdraws east and is followed up for a short time before the reinforcing infantry and bn tac pty are delivered to the D Coy area.
1850 hrs	B Company 6 RAR had been returning from an earlier patrol but were held short of the 1 ATF base. Eventually they were turned around and re-joined D Company at about 1850.
1900 hrs	Enemy break contact and withdraw eastwards. CO 6 RAR assumes command.

Appendix D: Triage Classification

Triage is the process used to sort casualties according to their need for treatment. The first recorded case of triage is reported to be by surgeons in the Napoleonic Army, where soldiers requiring urgent care were attended to promptly irrespective of rank or lineage (Kennedy et al, 1996). While triage has evolved since then, the principles have remained the same. The objective is to efficiently distinguish and classify casualties according to their need for medical attention. Today a simple system, for wide applicability, has been universally adopted for military and civilian triage classification (Lee, 2010).

- **Red Triage Tag (Immediate, T1, or Priority 1).** Patients whose lives are in immediate danger and who require immediate treatment.
- **Yellow Triage Tag (Delayed, T2, or Priority 2).** Patients whose lives are not in immediate danger and who will require urgent but not immediate medical care.
- **Green Triage Tag (Minimal, T3, or Priority 3).** Patients with minor injuries who will eventually require treatment.
- **Black Triage Tag (Expectant or No Priority).** Patients who are either dead or who have such extensive injuries that they cannot be saved with the resources at hand.

Within military medical practice, the triage tag may also indicate (but not determine) priority for evacuation. A T1 patient should be evacuated within 2 hours and 6 hours for a T2 patient. This reflects the severity of the injury, and urgency for treatment, and likelihood of survival.

Appendix E: Injury Profiles

There are many different ways to describe and classify wounds. A general description of the different types of wounds is described in Hospital Corpsman (US Navy, 2010, pp. 21-62 & 21-63), which as the advantage of being publically available. Military classification systems are similar, although not identical.

	Types of Wounds
Abrasion	Grazing caused by transverse action of a foreign object against skin
Avulsion	Removal of tissue or organ by force (and not by incision)
Ballistic Trauma	Puncture wound caused by projectile weapon
Contusion	Bruising caused by blunt trauma
Crushing Injury	Various injuries caused by extreme applied force
Incision	Cut caused by sharp object to tissue or organ
Laceration	Irregular wound caused by blunt impact to soft tissue
Puncture Wound	Penetration of skin and underlying areas by inserted foreign object

The Vietnam War typified close-combat encounters. The types of injuries experienced included increased incidence of wounds to the head, neck and chest which are expected when fighting from a prone position or from partial cover. The severity of ballistic trauma experienced upon gunfire depended on the type of projectile; namely its weight, but also calibre, shape and composition. The velocity and range travelled before lodgement of the round is also important.

Injuries due to blast-type munitions were also common. Overpressure of 100 PSI is lethal but the magnitude of the blast depends on the initial pressure wave, the duration of the overpressure, the medium in which it propagates, distance from the blast, and focusing due to the environment (Marks, 2002, pp. 30-2). Three types of injuries are inflicted (Horrocks, 2001).

1. **Primary Blast Injuries.** Inflicted by the explosive force of the blast. Typical injuries include air embolisms, haemorrhages in the liver and spleen, collapsed lungs, rupture of the eardrums, and displacement of the eyes from their sockets. Many injuries are not immediately detected and are not externally visible.
2. **Secondary Blast Injuries.** Inflicted by flying debris, fragments and other airborne particulates when they collide with the casualty. A range of injuries can occur including contusion, crushing injuries, incision, laceration, and puncture wounds. This class of injury also includes injuries inflicted by a secondary shockwave, for example generated inside a vehicle when the primary wave strikes external armour plating.
3. **Tertiary Blast Injuries.** Inflicted as a result of a casualty impacting with their environment. This is caused by the casualty being physically displaced by the primary blast.

Appendix F: Australian Company Formations

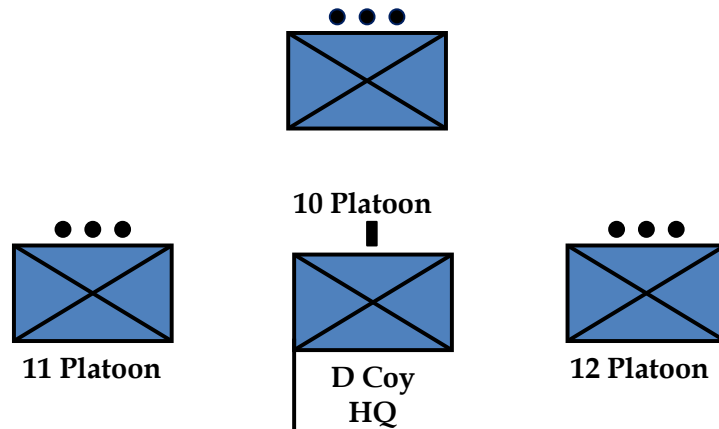


Figure 8: Australian company formation 'one up'

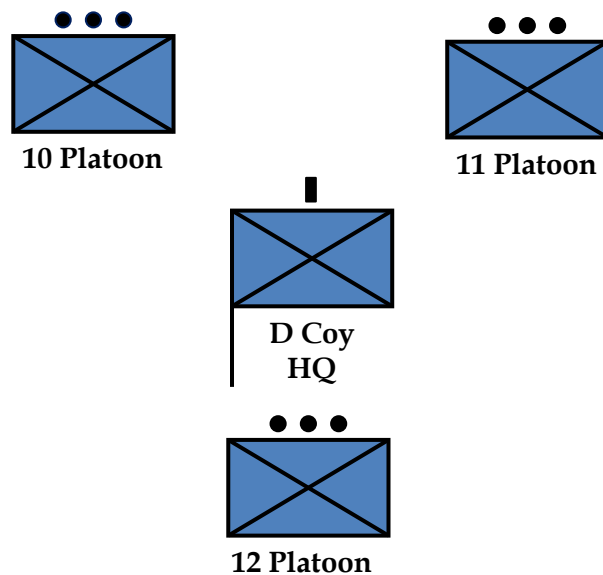


Figure 9: Australian company formation 'two up'

Appendix G: NetLogo Scripts

G.1. Agent Wounding

```

to-report wound [ my_agent ]

  ; do not target personnel who are unconscious or unable to fight
  let all-targets all-able-bodied my_agent
  if empty? all-targets [ report 0 ]
  let target random (length all-targets)

  let location random-float 100
  let severity random-float 100

  let loctxt "None"
  let triage "Not Urgent"

  if location < 14
  [
    set loctxt "Head"

    if severity < 50 [ set triage "Class I"]
    if severity >= 50 and severity < 57.9 [ set triage "Class II"]
    if severity >= 57.9 and severity < 67.7 [ set triage "Class III"]
    if severity >= 67.7 and severity < 87.9 [ set triage "Class IV" ]
  ]

  if location >= 14 and location < 21
  [
    set loctxt "Face"

    if severity < 8.6 [ set triage "Class I"]
    if severity >= 8.6 and severity < 11.5 [ set triage "Class II"]
    if severity >= 11.5 and severity < 12.9 [ set triage "Class III"]
    if severity >= 12.9 and severity < 34.3 [ set triage "Class IV" ]
  ]

  if location >= 21 and location < 23.5
  [
    set loctxt "Neck"

    if severity < 36 [ set triage "Class I"]
    if severity >= 36 and severity < 44 [ set triage "Class II"]
    if severity >= 44 and severity < 48 [ set triage "Class III"]
    if severity >= 48 and severity < 60 [ set triage "Class IV" ]
  ]

```

```

if location >= 23.5 and location < 36
[
    set loctxt "Thorax"

    if severity < 38.4 [ set triage "Class I"]
    if severity >= 38.4 and severity < 47.2 [ set triage "Class II"]
    if severity >= 47.2 and severity < 53.6 [ set triage "Class III"]
    if severity >= 53.6 and severity < 80 [ set triage "Class IV" ]
]

if location >= 36 and location < 46
[
    set loctxt "Abdomen"

    if severity < 28 [ set triage "Class I"]
    if severity >= 28 and severity < 41 [ set triage "Class II"]
    if severity >= 45 and severity < 61 [ set triage "Class III"]
    if severity >= 61 and severity < 92 [ set triage "Class IV" ]
]

if location >= 46 and location < 66
[
    set loctxt "Upper Limb"

    if severity < 2 [ set triage "Class I"]
    if severity >= 2 and severity < 4 [ set triage "Class II"]
    if severity >= 4 and severity < 5.5 [ set triage "Class III"]
    if severity >= 5.5 and severity < 20 [ set triage "Class IV" ]
]

if location >= 66 and location < 97
[
    set loctxt "Lower Limb"

    if severity < 4.8 [ set triage "Class I"]
    if severity >= 4.8 and severity < 8.7 [ set triage "Class II"]
    if severity >= 8.7 and severity < 11.9 [ set triage "Class III"]
    if severity >= 11.9 and severity < 33.5 [ set triage "Class IV" ]
]

if location >= 97 and location < 100
[
    set loctxt "Multiple Locations"

    if severity < 50 [ set triage "Class I"]
    if severity >= 50 and severity < 73.3 [ set triage "Class II"]
    if severity >= 73.3 and severity < 83.3 [ set triage "Class III"]
    if severity >= 83.3 and severity < 100 [ set triage "Class IV" ]
]

ifelse ( triage = "Not Urgent" )

```

```

[
  set AS_NFW AS_NFW + 1 ; Non-Fatal Wound
  ask my_agent [ set injured (replace-item target injured 1) ]
]
[

  let bleeding 0
  let current_rate 0
  let attachment "None"

  ask my_agent
  [
    let blood_ml ( item target blood_volume ) - 1
    set blood_volume ( replace-item target blood_volume blood_ml)

    ; 1 to 60 minutes
    if triage = "Class I" [ set bleeding 2500 / (1 + random 60) ]
    ; 61 to 360 minutes
    if triage = "Class II" [ set bleeding 2500 / (61 + random 300) ]
    ; 361 to 1440 minutes
    if triage = "Class III" [ set bleeding 2500 / (361 + random 1080) ]
    ; Greater than 1-day
    if triage = "Class IV" [ set bleeding 0 ]

    set bleeding floor bleeding
    set current_rate (item target bleed_rate)
    set bleed_rate (replace-item target bleed_rate (current_rate +
                                                         bleeding) )

    ; replace injury description with location of most serious wound
    if current_rate < bleeding
    [ set injury_at (replace-item target injury_at loctxt ) ]

    ; may become untreatable if currently treatable (reverse not poss)
    if item target treatable = 1
    [ set treatable (replace-item target treatable random 2 ) ]

    set attachment breed
  ]

  output-print ( word OP_Time ": AS Soldier (#" target " " attachment
                      ") wounded in " loctxt )

  output-print ( word OP_Time ": " triage " injury (" bleeding "
                                                         ml/min)")

  if current_rate > 0 [ output-print ( word OP_Time ": Sustained
                      Secondary Injury (" (current_rate + bleeding) " ml/min total)") ]

  output-print " "

]

report 1

end

```

G.2. Agent Bleeding

```

to agents-bleeding

  let total_KiA 0
  let total_WiA 0

  ask turtles with [color = blue]
  [
    let idx 0
    repeat unit_size
    [
      let my_loctxt item idx injury_at
      let my_condn item idx treatable

      let my_rate item idx bleed_rate
      let new_rate my_rate

      let my_volume item idx blood_volume
      let my_shock hemorrhage-class self idx

      ; auto injection
      if allow_auto_injection and my_shock > 1
      [
        set new_rate new_rate * (100 - intravenous_coagulants) / 100
      ]

      ; combat medics
      ifelse allow_combat_medics and distance one-of AS_B_chq < 50
      [
        set new_rate new_rate * (100 - standard_bandage) / 100
      ]
      [
        if allow_self_treatment and my_shock < 3
        [
          set new_rate new_rate * (100 - self_medicated) / 100
        ]
      ]
    ]

    ; patient will DoW not related to blood loss
    let new_volume (my_volume - my_rate)

    ; treating blood-loss may save patient
    if my_condn = 1 [ set new_volume (my_volume - new_rate) ]

    set blood_volume ( replace-item idx blood_volume new_volume )

    if (new_volume < 2500) [ set total_KiA (total_KiA + 1) ]
    if (new_volume < 5000) [ set total_WiA (total_WiA + 1) ]
  ]

```



```

if (new_volume < 2500 and my_volume >= 2500)
[
  output-type (word OP_Time ": !! AS Solder dies of wound to "
                                     my_loctxt )
  if my_condn = 0 [ output-type " (untreatable wound)" ]
  output-print " !!"
  output-print ""
]

if (item idx injured) = 1
[
  if (new_volume >= 5000) [ set total_IiA total_IiA + 1 ]
]

set idx (idx + 1)
]

set AS_KiA total_KiA
set AS_WiA (total_WiA - total_KiA)
set AS_IiA total_IiA

end

```

G.3. Calculation of Time

```

to calculate-OP_Time

  let hour (floor (ticks / 60))
  let minute ticks - hour * 60
  set OP_Time H_Hour + 100 * hour + minute

end

```

G.4. Haemorrhage Class

```

to-report hemorrhage-class [ my_agent idx ]

  let class -1 ; Dead ( >50% blood loss)
  ask my_agent
  [
    let my_volume item idx blood_volume
    let per 100 * my_volume / 5000
    set per 100 - per

    if per = 0 [ set class 0 ] ; Uninjured
    if per > 0 and per < 15 [ set class 1 ] ; Class I
    if per >= 15 and per < 30 [ set class 2 ] ; Class II
    if per >= 30 and per < 40 [ set class 3 ] ; Class III
    if per >= 40 and per < 50 [ set class 4 ] ; Class IV
  ]
  report class
end

```

G.5. Report if this Agent is Able-to-Fight

```

; Exclude agents if Dead, in Haemorrhagic Shock, or Heavy Bleeding
to-report fighting-fit [ my_agent idx ]

  let is_stable? false      ; Is Not Bleeding (may have minor injury)
  let is_gusher? false      ; Is Bleeding at rate of 30 ml/min or Worse
  let is_dead? false        ; Is Dead
  let is_shock? false       ; Is Hemorrhaging at Class II or Worse

  ask my_agent
  [
    let bleeding item idx bleed_rate
    if bleeding <= 0 [ set is_stable? true ] ; Not bleeding | transfusion
    if bleeding >= 30 [ set is_gusher? true ] ; Serious bleeding

    let shock (hemorrhage-class my_agent idx)
    if shock < 0 [ set is_dead? true ] ; Dead
    if shock > 1 [ set is_shock? true ] ; Class II or Worse

  ]

  if is_gusher? [ report false ]
  if is_dead? [ report false ]
  if is_shock? [ report false ]

  report true
end

```

G.6. Report All Agents Able-to-Fight

```

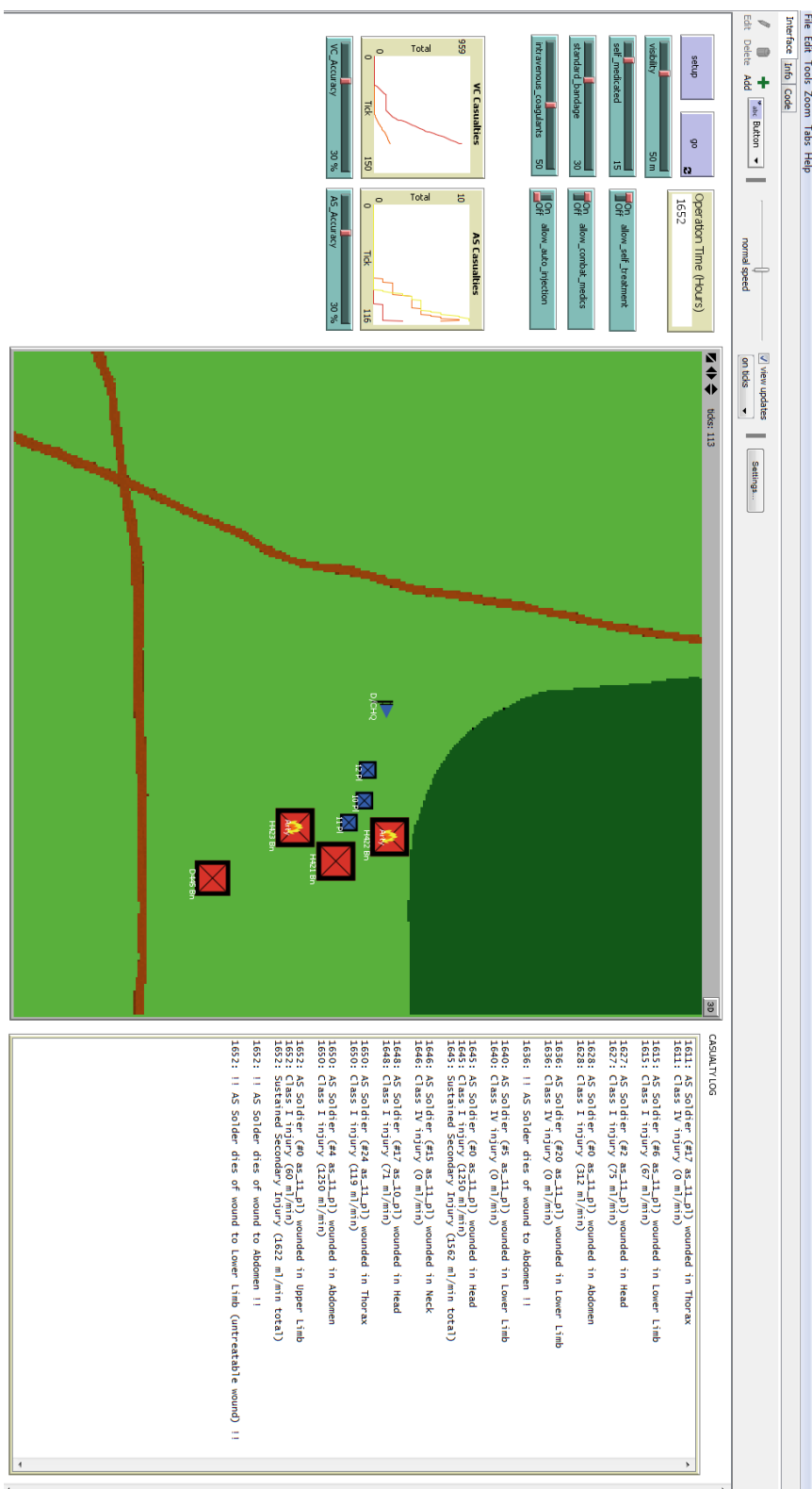
; Search agent and report all units which are still fighting-fit
to-report all-able-bodied [ my_agent ]

  let all-able []

  ask my_agent
  [
    let idx 0
    while [idx < unit_size]
    [
      let is_able fighting-fit my_agent idx
      if is_able [ set all-able (lput idx all-able) ]
      set idx (idx + 1)
    ]
  ]
  report all-able
end

```

Appendix H: Screenshot



Page classification: UNCLASSIFIED

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION DOCUMENT CONTROL DATA					
				1. DLM / CAVEAT	
2. TITLE Biotechnology on the Battlefield: An Application of Agent-based Modelling for Emerging Technology Assessment			3. SECURITY CLASSIFICATION Document (U) Title (U) Abstract (U)		
4. AUTHOR(S) Scott Wheeler and BRIG (ret.) Justin Kelly			5. CORPORATE AUTHOR Defence Science and Technology Organisation 506 Lorimer St Fishermans Bend Victoria 3207 Australia		
6a. DSTO NUMBER DSTO-TR-3087		6b. AR NUMBER AR-016-251		6c. TYPE OF REPORT Technical Report	
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16. DELIBERATE ANNOUNCEMENT No Limitations					
17. CITATION IN OTHER DOCUMENTS Yes					
18. DSTO RESEARCH LIBRARY THESAURUS Technology, Biomedicine, Combat models					
19. ABSTRACT Penetrating wounds are the most common injury incurred in military combat, resulting from both gunshot and shell fragmentation, and these wounds often result in mortality. However, in the future such fatal wounds might be treatable using advanced biotechnologies to control haemorrhaging and reduce blood-loss until medical evacuation can be completed. This study evaluates the operational implications of a new kind of intravenous coagulating agent. The efficacy of the drug is benchmarked against casualty data from the Vietnam War and assessed through a process of simulation in an agent-based combat environment. Finally, we conclude that the drug reduces mortality by 7%, within those casualties which are responsive to treatment.					

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